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الجامعة الأردنيـــــة
كلية الدراسات العليا

التاريـــخ: / /

نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

أنا الطالب: محمود حسن الرواشدة الرقم الجامعي: (8080144)
تخصص: هندسة النقل الكليـــــة: الهندسة والتكنولوجيا

عنوان الرسالة: Effect of lane width, Number of lanes
and grade on highway capacity in Amman

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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EFFECT OF LANE WIDTH, NUMBER OF LANES AND GRADE ON HIGHWAY CAPACITY IN AMMAN

By

Mahmoud Hasan Alkhazaleh

Supervisor

Dr. Adli Al-Balbissi, Prof

This Thesis was submitted in Partial Fulfillment of the Requirements For the Master's Degree of Civil Engineering in Transportation

Faculty of Graduate Studies

The University of Jordan

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COMMITTEE DECISION

This thesis / Dissertation (Effect of lane width , number of lanes and grade on highway capacity in Amman) was successfully defended and Approved on 09 /05 /2011

Examination committee	Signature
Prof. Adli Al-Balbisi (Advisor)	....
Prof.khair Jadaan (Member)	....
Dr.Mohammed Al-Trawneh (Member)	....
Dr.Mohammed Naser (Member)	....

DEDICATION

To my father soul

To my mother

To my brothers and sisters

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List of Abbreviations

DF= degrees of freedom

E_t= passenger car equivalent for trucks and buses

FFS=free flow speed

f_{ds}= adjustment factors for , directional split

f_g = adjustment factors for gradient

f_s= adjustment factors for shoulder conditions

f_{smv}= adjustment factors for , slow moving vehicles

f_{ui}= adjustment factors for unevenness index

f_w= adjustment factors for lane width

GAM= Greater Amman Municipality

MS=mean of squares

P_t= percentage of trucks

q= traffic flow (veh/h)

R-sq= coefficient of determination

R-sq (adj) = adjusted coefficient of determination

S= standard deviation

SS= sum of squares

Uş = space mean speed (km/h)

Uŧ = time mean speed (km/h)

V_m= Speed at capacity (km/h)

EFFECT OF LANE WIDTH, NUMBER OF LANES AND GRADE ON HIGHWAY CAPACITY IN AMMAN

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ABSTRACT

This study examines the effect of some characteristics of highway geometry and traffic flow on the lane capacity of selected highways in Amman, the capital of Jordan. Three congested highway sections were selected for the purposes of this study. The study used and analyzed two categories of data. The first category included some geometric details of the selected highways (grade, lane width and number of lanes). The second category included traffic flow data (the traffic volume, the speed of traffic, percentage of trucks) at these selected highway sections; traffic flow data was taken from loop detectors.

Two types of regression models were used for the analysis of data. First type, a simple regression analysis was performed to identify the relationship between traffic flow and speed on each lane of selected streets, which was used to determine the actual capacity of each lane. The second type of regression analysis performed was multiple regression analysis, which was used to identify the effect of some road geometry and traffic flow characteristics on lane capacity, these factors were, grade, lane width, number of lanes, location of lane and the percentage of trucks passing through the studied sections. The results of the capacity analysis showed that the design capacity values in Amman highways were higher than actual capacity. The difference between the actual and design capacity reached up to 35%.

The analysis showed that speed and flow were related (inversely), the model has performed to identify the effect of some road geometry and traffic flow characteristics on lane capacity. Generally, the developed model showed there was a clear effect of the studied factors, except grade, on lane capacity at confidence interval 95%. The capacity of each lane was found to be different from another lane, even in the same section and direction.

1. INTRODUCTION

1.1 General Introduction:

Traffic congestion is a serious problem, affecting the economy, environment and quality of life in our cities. In designing highways, traffic engineers must anticipate the amount and type of traffic that will use the road, in order to make the highway match its anticipated use. Vehicle capacity is defined in the highway capacity manual 2000 HCM (2) as the maximum number of vehicles that can pass through a given point in street during a given period under prevailing roadway, traffic, and control conditions. This was based on the assumption that there is low effect from downstream traffic operation, capacity is an important factor in evaluating the efficiency of the transportation system and highway networks, also, provides as an indicator on the success of traffic planning , operations, and policies used in the management of the highways system.

Knowledge of capacity of a road and the factors affecting it is important in planning, design and operation of transportation system. A main objective of capacity analysis is to estimate the maximum number of vehicles that a facility can carry with reasonable safety during a specified time period. However, facilities generally operate poorly at or near capacity. Accordingly, capacity analysis also estimates the maximum amount of traffic that a facility can carry while maintaining its specific level of operation

Studying the traffic characteristics such as, capacity and free flow speed, are primary for describing the efficiency of traffic networks and developing macroscopic traffic models.

1.2 Problem Definition:

In the city of Amman, the state of the practice highway capacity used now in all traffic wasn't measured but estimated (based on HCM 2000). However, the actual capacity is not the same as estimated because the traffic, control and geometry conditions are very different from the case study used for HCM procedure, and consequently, the outputs of traffic and transportation analyses have an error due to using the estimated capacity as actual capacity. This difference in capacity estimates' affects the effectiveness of planning for Amman transportation system and the traffic operations analysis of its roads network. Moreover, it affects the management plans and analysis for traffic operations on Amman.

1.3 Research Objectives:

The main objectives of this study are to identifying the actual capacity and the effect of some factors on lane capacity of congested highways that are located in Amman metropolitan area. Specifically, the study will investigate the following:

- Evaluation of midblock lane capacity for selected urban streets in Amman using speed – flow diagrams

- Identifying the influence of grade on lane capacity

- Identifying the influence of lane width on lane capacity.

- Identifying the influence of number of lanes and location of lane on lane capacity.

- Identifying the influence of percentage of trucks in the traffic stream on lane capacity.

The study framework includes:-

- Determining the study areas that represent congested highway sections satisfying the desired variations in selected factors, point of the study must be at a sufficient distance from nearest intersection to ensure minimal effect from downstream traffic operation ,so we can evaluate midblock capacity , sections include :-

  a. Zahran street (between 4^{th} and 5^{th}) circles.
  b. Queen Alia street (front of Regency Hotel).
  c. Alquds street (between(alquds- aldustor) streets intersection and (Ali ben abe taleb street)

- Measuring, collecting and calibrating data.
- Performing the needed statistical analysis to develop models that show the effects of selected factors on lane capacity.

2. LITERATURE REVIEW

Vehicle capacity is defined in the highway capacity manual 2000 HCM (2) as the maximum number of vehicles that can pass through a given point in street during a given period under prevailing roadway, traffic, and control conditions.

Many factors affect highway capacity and may be grouped into three main categories:-

Highway Conditions: consist of geometric and other elements, such as:-

- Grade.
- Number of lanes.
- Lane widths.
- Shoulder widths and lateral clearance.
- Design speed.
- Horizontal and vertical alignments.
- Access density.

Traffic Conditions: Traffic flow conditions that affect capacity include:-

- Vehicle type.
- Directional flow and lane distribution

Control Conditions: For interrupted flow, the type of traffic control used affect highway capacity with traffic signal having the highest effect on capacity than other control types.

Traffic flow data is needed for the purpose of this study, there are different methods that could be used to collect traffic flow data, including:-

- Manual collection on the site.
- Collecting data using digital cameras that used are to record videos of traffic flow on highways.
- Using loop detectors fixed on highways. Loop detectors are used to count vehicles passing or arriving at a certain point, loop detectors can record speed and length of vehicles passing a certain point, for instance approaching a traffic light, and in highway traffic management. An insulated, electrically conducting loop is installed under the road. An electrical voltage is generated when iron or steel body passes close to the loop; this method was used in our study, Figure (1.2) show the loop detectors.



Figure (1.2) loop detectors

In this study we used fundamental speed flow model to evaluate highway capacity. Fundamental speed flow diagrams are widely used to calculate the maximum flow (capacity). The parabola speed flow diagram suggests that speed is free flow when the density approaches zero; it also suggests that as the flow increases the speed decreases. The model is shown in figure (2.2).

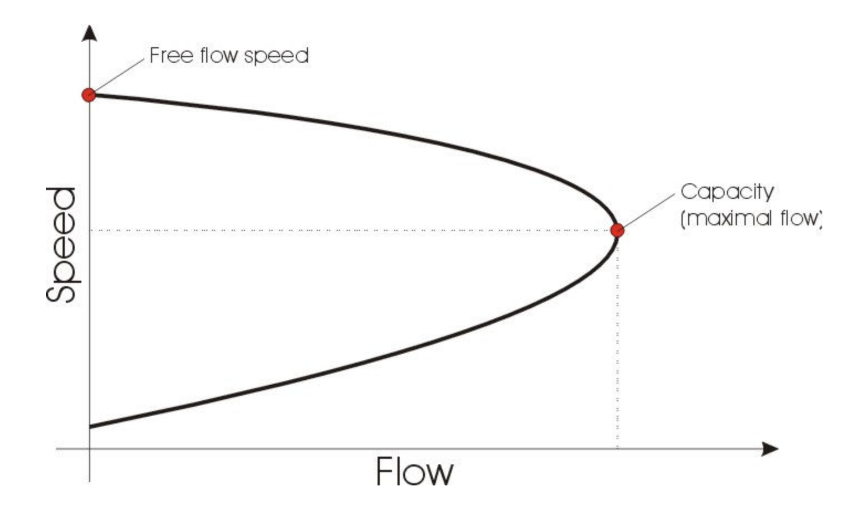


Figure (2.2): Fundamental Speed –Flow Diagram [4]

Numerous studies were conducted to analyze the effect of mixed highway, traffic and control conditions on highway capacity. Data for these studies were collected using different methods; different programs and different statistical methods were employed to create models to calculate highway capacity under different conditions.

A study in china (9) attempted to show the impact of the number of lanes on highway capacity. The study areas were urban locations in the north of Beijing in China. Three types of divided highway sections, which have two, three and four lanes, were selected for data collection. Capacities on these sections were highly influenced by number of lanes; other factors had small effect on capacity of these sections. Data for each lane in studied locations were collected using digital camera during the summer and fall of 2004 in one direction over 15 minutes intervals, data included speed, density and vehicle classification. The relationship between the capacity of the highway and its number of lanes was determined by using statistical analysis methods. Variance analysis has been used for modeling the effect of the number of lanes on capacity. The results showed that average capacity per

lane was inversely related to number of lanes on uninterrupted highway segment. The marginal decrease rate of average capacity per lane with increasing number of lanes was 6.7%. This is due to the marginal decrease of lane capacity that occurred when number of lanes increased. The study suggested that manuals of highway capacity should be revised to improve the planning and design of road network. The study recommended that the marginal decrease of highway capacity due to increasing number of lanes should be affected the decision on adding lanes or constructing a new parallel road when travel demand exceeds capacity of the existing road.

A study (6) was conducted to estimate capacity of two-lane, two-way highways under specific conditions: the presence or absence of passing zones, driveways, horizontal curves, and grades by developing a microscopic simulation model. Highway Capacity Manual 2000 suggests the capacity of two-lane, two-way highways to be 1,700 pcphpl. This value doesn't take into account the effect of the variety of traffic, geometric, and driver conditions that may exist on two-lane, two-way highways. This study was performed using microscopic simulation model developed by MATLAB 6.5 program. The capacity with ideal conditions (i.e., 100 percent no-passing zone, all passenger cars and commuters drivers, level terrain section, 12' lane width, 6' shoulder width) for one lane was estimated in this study to be 2,100 pcph at average free flow speeds of 60 and 70 mph respectively, 2.000 pcph at 50 mph average free flow speed, and 1,850 pcph at 40 mph average free flow speed. These values of estimated capacities were higher than those recommended by the 2000 HCM's for one direction. The presence of passing zones was not found to increase capacity. Capacity

values were evaluated for the presence of a driveway, a horizontal curve, a grade, and different percentages of trucks in the traffic stream. These factors were found to reduce capacity between 5 and 38 percent.

Shyam Venugopal et al.(11) presented a study to investigate potential capacity influencing factors to develop capacity prediction models. The studied factors included wind, rain, heavy vehicles, lane drop type (left or right), control by a police, and presence of a novel traffic control system called Indiana Lane Merge System (ILMS). This study was conducted for two-lane roadways on rural freeway with one lane dropped. The main data needed for the analysis was traffic volume and speed data. Traffic speed and volume were collected from April 1999 to July 1999. The data was collected using loop detectors fixed on both entrances of the work zone.

The collected data was analyzed using four statistic methods: descriptive summary, covariance analysis, linear regression, and non-linear regression analysis. The study results showed that the studied factors (rainfall, heavy vehicles, police presence, and ILMS presence) reduced work zones capacity. The reduction in capacity value caused by rain and heavy vehicles was similar to the reduction observed on freeway sections without work zones. The magnitude of reduction for the presence of ILMS was (5-6%). This effect may be temporary and may be decreased with increasing the familiarity of drivers with the system upon time. The highest reduction (14%) was observed during police presence near the work zone.

Jittichai,Chulalongkorn (5) showed the factors affecting urban street bottleneck capacity on Henry Dunant Road, a highly congested urban street in Bangkok. Detailed and accurate observations on the studied street showed

that the street bottleneck capacity is affected by factors such as interrupted U-turns from the opposing direction, illegal blocking parked cars, and interrupted crossover right turns from an access road. Traffic data for the studied location was collected by video cameras during four days to analyze the effect of these factors on street bottleneck capacity.

The study results showed that the bottleneck capacity might not significantly be reduced by increasing of U-Turns volumes but the bottleneck capacity would be increased by restricting U-Turn movements with the average ratio of U-turns to through cars of about 1:5, i.e., one vehicle moves U-Turn is equivalent to about five vehicles move through. The study showed also, if right turn volume increased by 68 vph, the bottleneck capacity would drop by 200 vph in street. The average ratio of right turn volumes to capacity change is about 1:3, i.e., one vehicle makes right-turn is equivalent to about three vehicles move through.

Jasmina Bunevska et al. (3), presented a study that aims to develop speed-flow regression models for passenger cars and heavy vehicles in the interrupted traffic stream, a relationship between parameters was performed based on empirical data.The speed and flow data was required to achieve the purpose of the study; the speed data was determined by conducting studies for running times, travel times and delays to develop a speed – flow curves for passenger cars and heavy vehicles.

Flow data were collected manually at peak hour, by (40) persons at fourteen (14) locations and categorized based on vehicle types, directions and turning movements. The speed-flow regression models were developed using the least squares and multiple regression methods. The results of the study show

that the “speed-flow” curves can be considered a good indicator to assess and analyze traffic operational performance and level of service (LOS).

A study (4) was presented during Annual Conference on Intelligent Transportation Systems (Portugal).The study attempted to estimate the effect of environmental conditions like rain and snow on traffic characteristics of urban roads. Studied traffic characteristics were capacity and free flow speed, which are primary for describing the efficiency of traffic networks and developing macroscopic traffic models.

To achieve the purpose of the study; speed and flow data were recorded from 35 fixed loop detectors on roadside of major arterial road. Loop detectors are fixed on approach of a signalized intersection in the urban area of Vienna (Austria), the distance was 250 meter from traffic signal to minimize the effect of traffic queue developed during red phase. Flow and speed data were provided by the detectors in a one minute aggregation interval i.e. traffic flow was accumulated and vehicle speed was averaged.

The results of the study showed that the capacity was reduced up to 10% and free flow speed was reduced up to 30% approximately depending on intensity and type of precipitation.

Chandra (10) studied the effect of some parameters on capacity of two-lane urban roads under mixed traffic conditions and to propose adjustment factors for each parameter .The selected parameters were grade, lane and shoulder width, traffic composition, directional split, the presence of slow moving vehicles and pavement surface conditions.

To achieve the purpose of the study, data including grade, road width, shoulder type and width of shoulder, the pavement roughness (measured using British Towed fifth wheel

bump integrator) ,speed and volume were collected at more than 40 sections of two-lane roads. The actual capacity of each section was obtained by developing speed-volume relationship. The adjustment factors for each parameter were also proposed. The study concluded that the estimated capacity of a two-lane road was 3140 pcu/h under ideal conditions for selected parameters i.e. all adjustment factors values were equal to 1.00. However, under mixed traffic conditions a capacity of 3100 pcu/h was suggested. This value is affected by parameters which were selected in this study. The actual capacity of a two-lane road under mixed traffic conditions is as follows.

$$C_a = C_b.f_g.f_w.f_{ds}.f_{smv}.f_s.f_{ui}$$ [10]

(2.1)

Where,

C_a = actual capacity under prevailing traffic and roadway conditions (pcu/h)

C_b = basic capacity (3100 pcu/h)

f_g, f_w, f_{ds}, f_{smv}, f_s, and f_{ui} are the adjustment factors for gradient, lane width, directional split, slow moving vehicles, shoulder conditions and unevenness index .The study provided values of each of these adjustment factors.

Another study (12) aimed of developing a simulation model to replicate heterogeneous traffic flow on urban roads of developing countries. The study dealt with the application of the model to derive passenger car unit (PCU) values for the different types of vehicles in heterogeneous traffic streams.

Based on the simulation study, the results showed that the service volumes at LOS C for one-way traffic flow on 24.0 ft and 36.0 ft wide road spaces were 2,250 and 3,150 passenger car unit (PCU) per hour respectively.

The study showed that the effect of heterogeneity of traffic on the variable passenger car unit (PCU) values was marginal. This is because the difference lies between 4.3 and 8.8 percent for service volume values between cars-only and heterogeneous traffic streams.

In Jordan there are no previous studies available that are related to the actual capacity of highways despite its importance .This study aims the capacity and the effect of some geometry and traffic characteristics factors on it.

3. DATA COLLECTION

3.1 Data Required:

To achieve the objectives of this study, two categories of data are required :

A. Details of the geometry for each selected section that included:-

- Grade
- Number of lanes
- Lane width

B. Detailed traffic flow data for the studied sections, which include:-

- Traffic volume
- Speed
- Length of vehicles passing through the studied sections

3.2 Data Collection Procedures:

The data collection procedure comprises the following steps:

1. Collecting data was determining the study areas; the selected sections must be congested, with a sufficient distance from nearest intersection to minimize effect from downstream traffic.
2. Measuring the grade, lane width and recording the number of lanes of each section. This step was performed using a total station surveying device to give accurate results.
3. Loading traffic flow data from a computer in Amman municipality which is wirelessly connected with loop detectors on the site.

3.3 Collected Data:

3.3.1 Description of sites

Three congested sections that are located in Amman metropolitan area were selected for the purpose of the study. The sites were selected in a way that the effects of other factors not included in the study on capacity are minimized i.e. not too far from the ideal conditions. The selected sections are equipped with loop detectors and carry high traffic volume; the sections are vital and classified by Amman master plan as arterial highways. The selected sites are:

1) A section along Zahran Street that located between 4^{th} and 5^{th} circles, This section is part of a multilane divided highway with two lanes per direction, many access points are observed, the section carries high traffic volume.
2) A section located along Queen Alia Street (between aldakhlyeh and almadeneh circles), this section is a multilane divided with three lanes per direction and carry high traffic volume, the lanes are not wide enough, many access points are observed .
3) A section located at the beginning of Alquds Street (beside main offices of greater Amman municipality). This section is a multilane divided with two lanes per direction and carry high traffic volume; the lanes are not wide enough. illegal stoppage and park were observed.

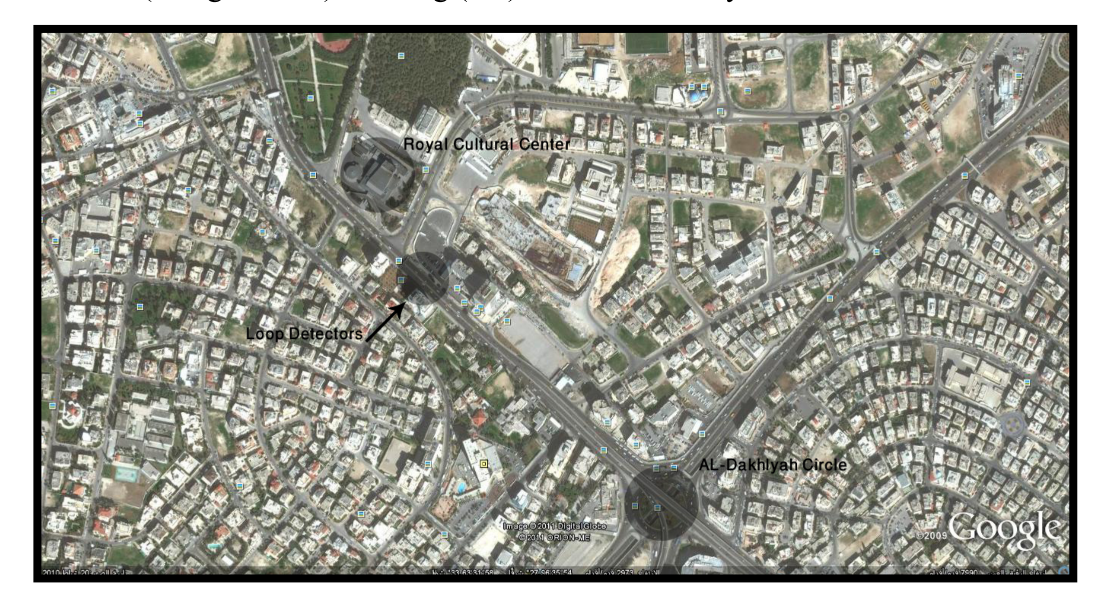
In this study we selected three sections only because the remaining sections which equipped with loop detectors aren't satisfying the criteria for

evaluating midblock capacity despite of many of other sections equipped with loop detectors are congested.

Point of study (loop detectors location), must be located with a sufficient distance from nearest intersections to minimize the effect of downstream traffic. Aerial photos for the selected locations are shown in figures 3.1, 3.2 and 3.3. Figures 3.4, 3.5 and 3.6 show sketches of loop detectors and lanes at the same locations .



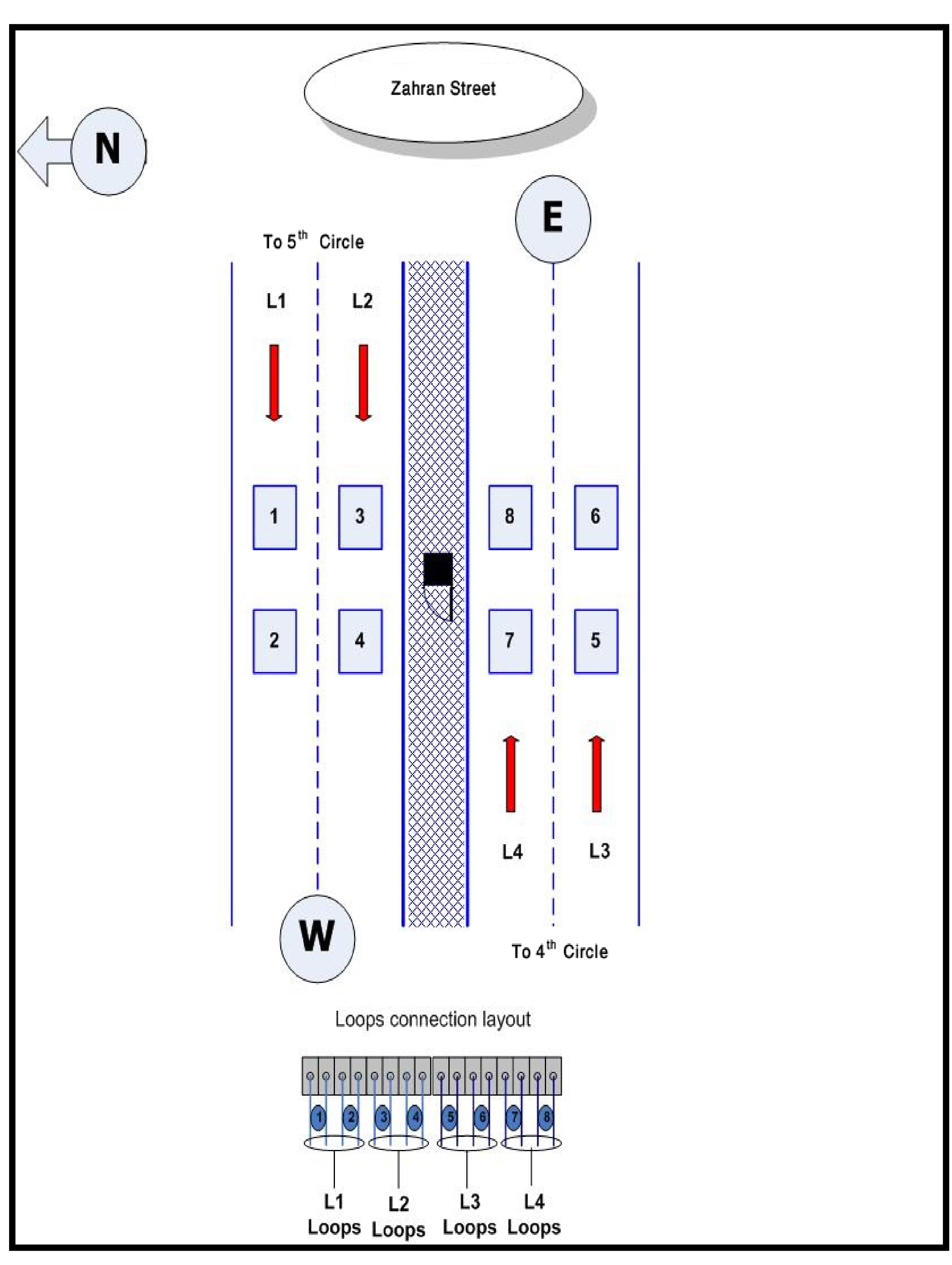
Source (Google Earth)   Fig (3.1) location of study - Zahran Stree



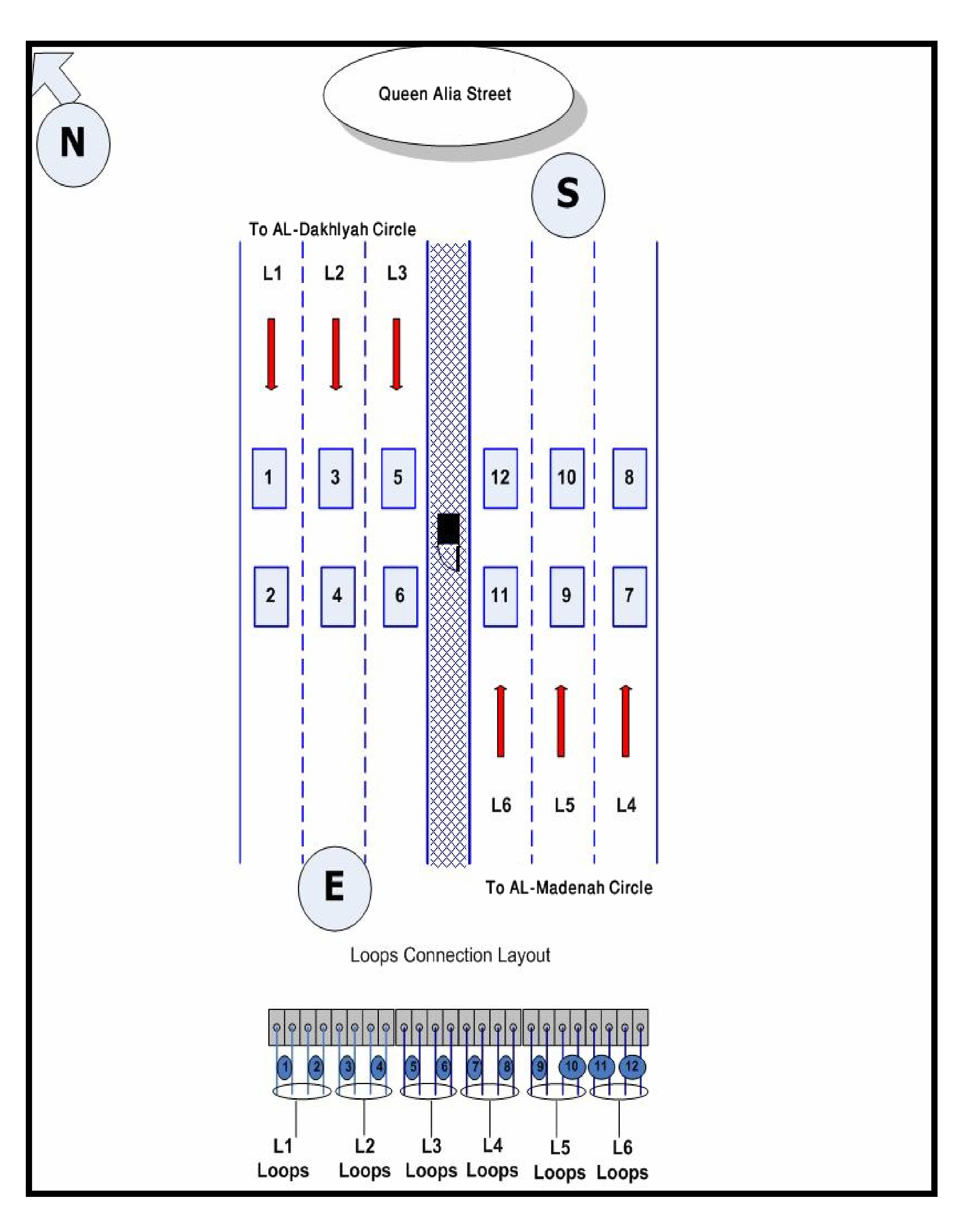
Source (Google Earth)   Figure (3.2) location of study – Queen Alia Street



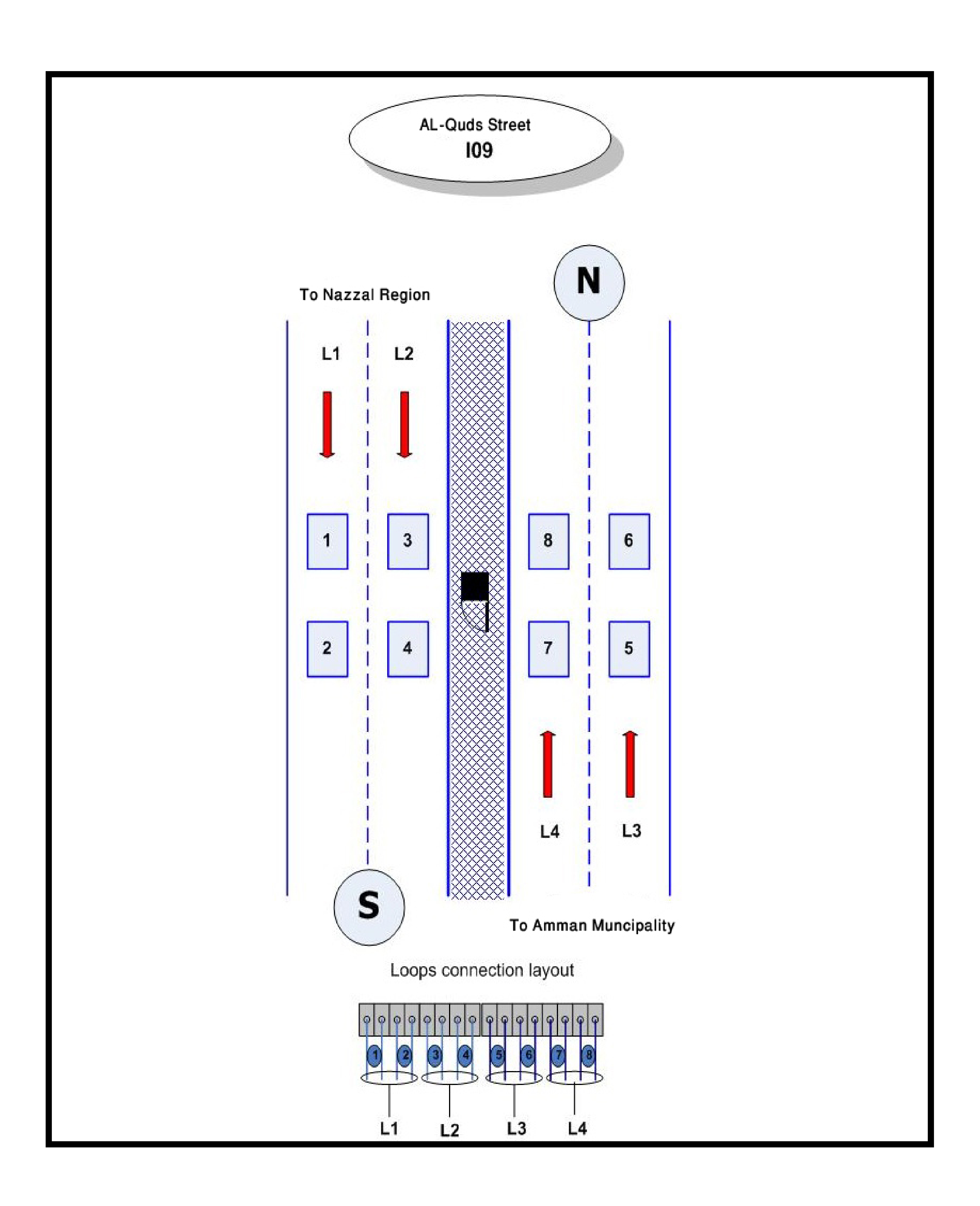
Source (Google Earth) Fig (3.3) location of study – Alquds Street



Source (Greater Amman municipality) Figure (3.4): loops detectors – Zahran Street



Source (Greater Amman municipality) Figure (3.5): loop detectors– Queen Alia Street



Source (Greater Amman municipality)

Figure (3.6): loop detectors – Alquds Street

3.3.2 Geometric Data:-

The road geometric features affecting capacity of highway and considered in this study included, grade, lane width and number of lanes . This data were collected for the selected locations using a total station and the results are as summarized in Table (3.1)

Table (3.1): Values of lane width, grade and number of lanes for the selected locations

Street Name	Lane Width(meter)						Grade%	Number of lanes (for one direction)
	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6		
Zahran	3.52	3.10	3.40	3.55	-	-	4.10	2
Queen Alia	2.80	3.10	2.90	2.75	2.85	2.95	0.80	3
Alquds	2.60	3.00	2.65	2.95	-	-	2.30	2

3.3.3 Traffic Flow Data:

Traffic – related data for each lane were extracted from the loop detectors installed by Greater Amman Municipality (GAM) at the selected locations in Amman. Loop detectors are fixed on each lane of selected sites and can record the speed and length of each vehicle passing through it. The data were collected for twelve working days between Dec-2010 and Mar-2011 .Samples of Excel sheets that show the data recorded by loop detectors are shown in tables (3.2) and (3.3).

Table (3.2): sample of excel sheet of the collected traffic flow data (speed and volume)

Site ID:	Queen Alya		City:	Amman
Site Reference :	I03		County:	Jordan
Start Date:	22/12/2010	Start Time :	12:00 AM	
End Date:	23/12/2010	End Time :	12:00 AM	

Date	Time	Lane	Speed												
			0010	0015	0020	0025	0030	0035	0040	0045	0050	0055	0060	0065	0070
22/12/2010	12:15 AM	1	0	2	0	0	0	0	1	1	10	11	5	9	3
22/12/2010	12:15 AM	2	4	10	1	0	0	0	2	3	6	20	34	36	33
22/12/2010	12:15 AM	3	0	7	0	0	0	0	0	0	0	2	1	4	21
22/12/2010	12:15 AM	4	3	1	1	0	3	0	4	3	4	3	2	1	4
22/12/2010	12:15 AM	5	3	5	1	1	1	2	9	11	13	19	30	23	25
22/12/2010	12:15 AM	6	1	5	0	0	0	0	0	0	0	2	6	13	24
22/12/2010	12:30 AM	1	0	1	0	1	1	4	0	3	8	6	10	4	6
22/12/2010	12:30 AM	2	0	4	1	0	0	1	1	6	13	10	28	28	33
22/12/2010	12:30 AM	3	0	6	2	0	0	0	0	0	0	0	2	7	20
22/12/2010	12:30 AM	4	2	0	0	0	0	0	4	4	6	3	2	4	0
22/12/2010	12:30 AM	5	3	5	0	0	0	0	2	7	7	22	26	31	12
22/12/2010	12:30 AM	6	0	0	1	0	0	0	0	0	0	2	3	12	11
22/12/2010	12:45 AM	1	0	2	0	0	0	1	3	0	6	8	6	4	2
22/12/2010	12:45 AM	2	2	5	0	0	0	0	2	4	6	14	17	27	21
22/12/2010	12:45 AM	3	0	2	0	0	0	0	0	0	0	0	3	3	13
22/12/2010	12:45 AM	4	1	0	0	0	2	3	4	3	0	2	3	1	0
22/12/2010	12:45 AM	5	2	1	1	1	0	2	3	4	7	18	22	18	21
22/12/2010	12:45 AM	6	0	1	1	0	0	0	0	0	1	2	3	4	14

Table (3.3): sample of excel sheet of the collected traffic flow data (length of vehicle)

Site ID:	Queen Alya		City:	Amman			
Site Reference:	I03		County:	Jordan			
Location:							
Start Date:	22/12/2010	Start Time:	12:00 AM				
End Date:	23/12/2010	End Time:	12:00 AM				

			Length				
Date	Time	Lane	0055	0090	0130	0250	>0250
22/12/2010	12:15 AM	1	46	3	0	0	0
22/12/2010	12:15 AM	2	186	24	3	1	0
22/12/2010	12:15 AM	3	103	16	0	0	0
22/12/2010	12:15 AM	4	28	4	0	0	0
22/12/2010	12:15 AM	5	165	13	1	0	0
22/12/2010	12:15 AM	6	106	12	0	0	0
22/12/2010	12:30 AM	1	47	3	0	0	0
22/12/2010	12:30 AM	2	168	25	1	1	0
22/12/2010	12:30 AM	3	88	13	0	0	0
22/12/2010	12:30 AM	4	23	2	0	0	0
22/12/2010	12:30 AM	5	134	14	0	1	0
22/12/2010	12:30 AM	6	91	4	0	0	0
22/12/2010	12:45 AM	1	37	2	0	0	0
22/12/2010	12:45 AM	2	152	17	0	0	0
22/12/2010	12:45 AM	3	61	3	2	0	0
22/12/2010	12:45 AM	4	20	1	0	0	0
22/12/2010	12:45 AM	5	123	9	1	0	0
22/12/2010	12:45 AM	6	80	7	0	0	0

- Lane 3- Zahran Street was excluded from the study because a technical problem occurred at this lane.

4. METHODOLOGY OF ANALYSIS

4.1 Correction of traffic flow data:-

Loop detectors are fixed on each lane, which may lead to double or triple counting of vehicle which isn't committed to its lane. Therefore, the traffic volume counted by loop detectors will be higher than the true volume. For this reason, correction of traffic flow data is needed to achieve accurate results in this study.The correction procedures were performed as follows:-

- Setting up a digital camera on each studied road section and recording a video (21 hours divided on three days) for the traffic flow.
- Counting visually the number of vehicles on video for each lane of sections.
- Comparing number of vehicle counted from the video with those counted by loop detectors.
- After comparing, it was observed that loops detectors gave volume larger than real situation (by video) because drivers weren't adhering to their lanes.
- Calculating reduction percent for flow according to equation (4.1).

$R= (q_d-q_v)/q_d$ ………… (4.1)

Where

R= Reduction Percent

q_v= volume by video

q_d= volume by loop detectors

Actual volume = $q_d - (q_d.R)$ (4.2)

4.2 Flow and Speed Analysis:

Traffic flow data were analyzed by creating excel sheets with the passenger car unit per hour representing flow data, and space mean speed representing speed data.

A. Passenger Car Equivalent Flow

AASHTO [1] classifies passenger vehicles length less than 5.79 m as passenger cars and other vehicles are classified as buses and trucks. Equation (4.3) was used to calculate passenger car equivalent flow.

$$q \text{ (pcu/h)} = ((1+Pt\times (Et-1)) \times \text{number of veh/h} \quad (4.3)$$

Where:-

q= flow (pcu/h)

Pt = percentage of buses and trucks = (number of vehicles which have length >5.50m) / total number of vehicles

Et = the passenger car equivalent for buses and trucks

B. Determination of Space Mean Speed:

Time mean speed is the arithmetic mean of the speeds of vehicles passing a point on a highway during an interval of time. Space mean speed represents the harmonic mean of vehicles speed. Space mean speed is obtained by dividing total distance traveled by vehicles on a road section by the total time required by these vehicles to travel that distance. The type of speed which is used in flow-speed models is Space mean speed while loop detectors record the time mean speed of vehicles. Therefore, it is necessary to convert time mean speed to space mean speed .In the study; we use weighted average method to evaluate average space mean speed. Equation (4.4) shows a general formula to convert time mean speed to space mean speed [8].

$Ut = Us + \square^2 / Us$ [8] (4.4)

Where:

Us = average space-mean speed

Ut = average time-mean speed

4.3 Methodology of Capacity Analysis:

The study utilized MINITAB and Excel programs for the statistical analysis of the input traffic flow data, speed and flow data were used for evaluating the actual capacity for each lane of the selected sections. The quadratic regression analysis was used to create speed - flow models for the calibrated speed-flow data. Actual capacity was obtained by averaging the maximum flow for each day of study period, each maximum flow value for one day was taken by averaging the maximum flow values for two or three hours (Am and Pm hours) during that day, theoretical capacity was obtained mathematically by derivation the flow speed equation.

5. ANALYSIS OF DATA

The data were collected, calibrated and analyzed for each lane of selected locations

5.1 Data Correction Results:

The results of calibrations are summarized in table (5.1):-

Table (5.1):-Reduction percent for traffic volume counted by loop detectors

Section	% of reduction					
	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Zahran	6	8	N.A	7	-	-
Queen Alia	6	21	11	5	19	10
Alquds	7	6	9	9	-	-

The results show that the middle lanes have the highest value of reduction, due to the lane changing and the Encroachment from the vehicles on left and right lanes.

5.2 Evaluation of Adjusted Flow and Speed:-

The Passenger Car Equivalent Flow and weighted average for space mean speed were evaluated by using excel program, sample calculations were done using excel sheet are shown in appendix A.

5.3 Capacity Analysis:

The speed –flow models were developed for each lane of the selected sections. Quadratic regression analysis was used to develop a speed - flow model for speed –flow data .Theoretical capacity and free flow speed values

were calculated mathematically by differentiating the resulting flow speed regression equation, due to the presence of unstable flow zone near capacity. The actual capacity was calculated by taking the average capacity of maximum flow of two or three hours in a day, each day had one value of average maximum flow (resulted by average maximum flow for two or three hours in a day).The net average value of actual capacity was calculated by averaging actual capacity values for the twelve days. Minitab program was used in the statistical analysis to develop the required models.

5.3.1 Zahran Street:

A-Lane 1

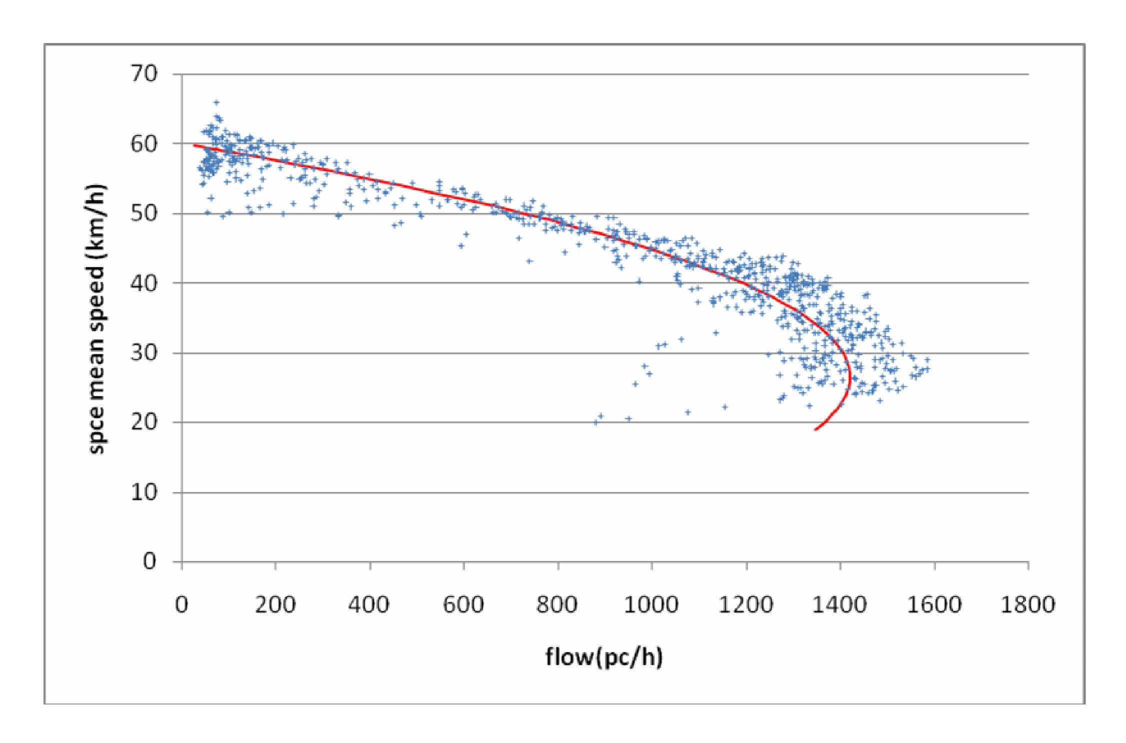


Figure (5.1) speed-flow model for lane 1-Zahran Street

Minitab outputs for flow (q) -speed (v) model for lane 1 of Zahran Street are shown in table 5.2.

The derived regression equation (confidence interval =95%) is:-

$$q = 780.0 + 52.14\ v - 1.07\ v^2$$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

Standard deviation (S) = 142.142 , coefficient of determination (R-Sq) = 92.2%,

Adjusted coefficient of determination R-Sq (adj) = 92.2%

Table (5.2):-Minitab outputs for analysis of variance (lane 1 –Zahran Street)

Source	DF[(1)]	SS[(2)]	MS[(3)]	F[(4)]	P
Regression	**2**	**253979700**	**126989850**	**6285.27**	**0.000**
Error	**1064**	**21497433**	**20204**		
Total	**1066**	**275477133**			

(1)DF: - degrees of freedom
(2)SS: - sum of squares
(3)MS: - mean of squares
(4) F= MS regression/MS error

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$$q = 780.0 + 52.14\ v - 1.07\ v^2$$

$$dq/dv= 52.14 - 2.14\ v$$

$$dq/dv = 0 = 52.14 - 2.14\ v \ldots\ldots\ldots\ v_m=24.29\ km/h$$

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation, we could find theoretical capacity (maximum flow).

$$q = 780.0 + 52.14\ v - 1.07\ v^2 = 780.0 + 52.14\ (24.29) - 1.073\ (24.29)^2 = 1413\ pcu/h$$

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$$q = 780.0 + 52.14\ v - 1.073\ v^2 = 0\ \ldots\ldots\ldots v = FFs = 60.60\ km/h$$

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period.

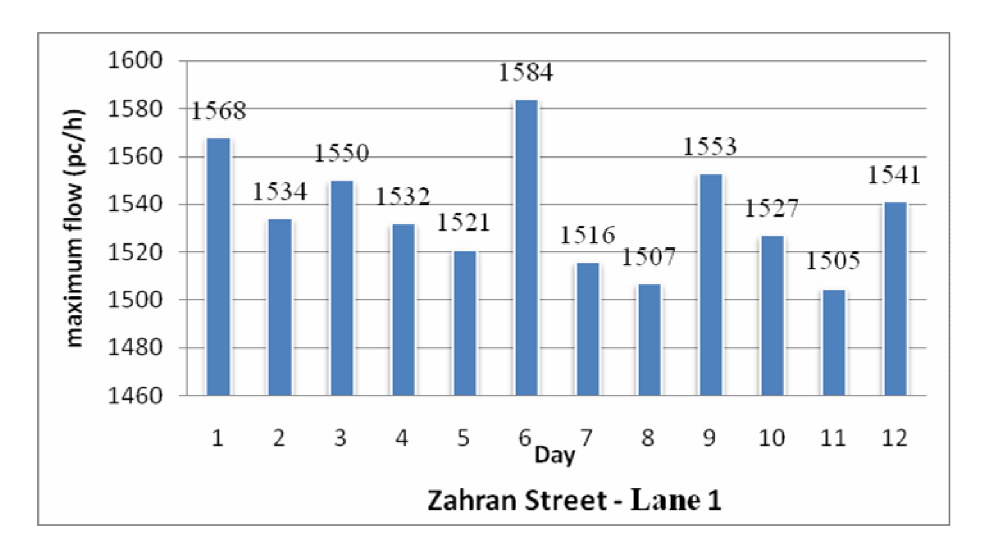


Figure (5.2) Actual capacity lane 1-Zahran street

From figure 5.2 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

$$q = (1541+1527+1553+1516+1521+1532+1550+1534)/8=1535\ pcu/h$$

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

B-Lane 2

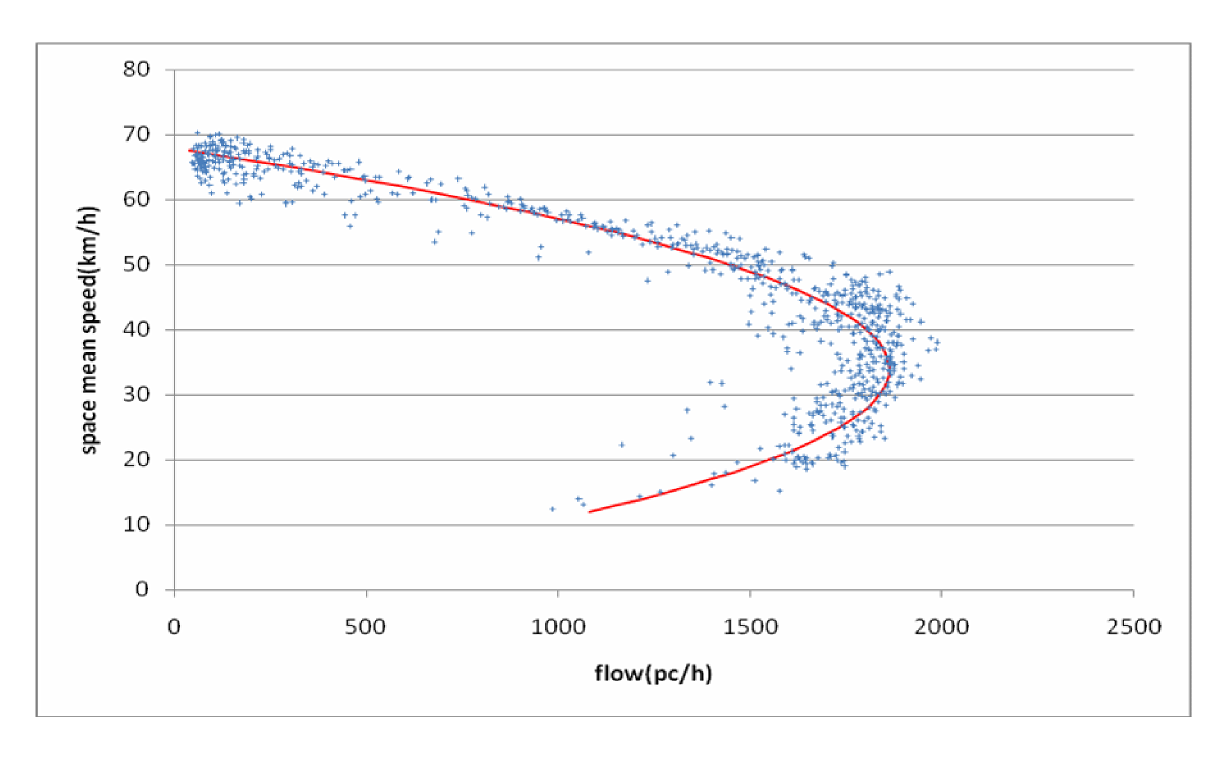


Figure (5.3) speed-flow model for lane 2-Zahran Street

Minitab outputs for flow (q) -speed (v) model for lane 2 of Zahran Street are shown in table 5.3.

The derived regression equation (confidence interval =95%) is:-

$q = - 28.80 + 110.9\ v - 1.62\ v^2$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 161.316 R-Sq = 94.3% R-Sq(adj) = 94.3%

Table (5.3):-Minitab outputs for analysis of variance for lane 2 –Zahran Street

Source	DF	SS	MS	F	P
Regression	2	459130839	229565419	8821.63	0.000
Error	1063	27662452	26023		
Total	1065	486793291			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = -28.80 + 110.9\,v - 1.62\,v^2$

$dq/dv = 110.90 - 3.25\,v$

$dq/dv=0= 110.90 - 3.25\,v$ .... $v_m = 34.13$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation, we could find theoretical capacity (maximum flow)

$q = -28.80 + 110.9\,v - 1.625\,v^2 = q = -28.80 + 110.9\,(34.13) - 1.62\,(34.13)^2 = 1863$ pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = -28.80 + 110.9\,v - 1.62\,v^2 = 0$........$v = FFs = 67.97$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period

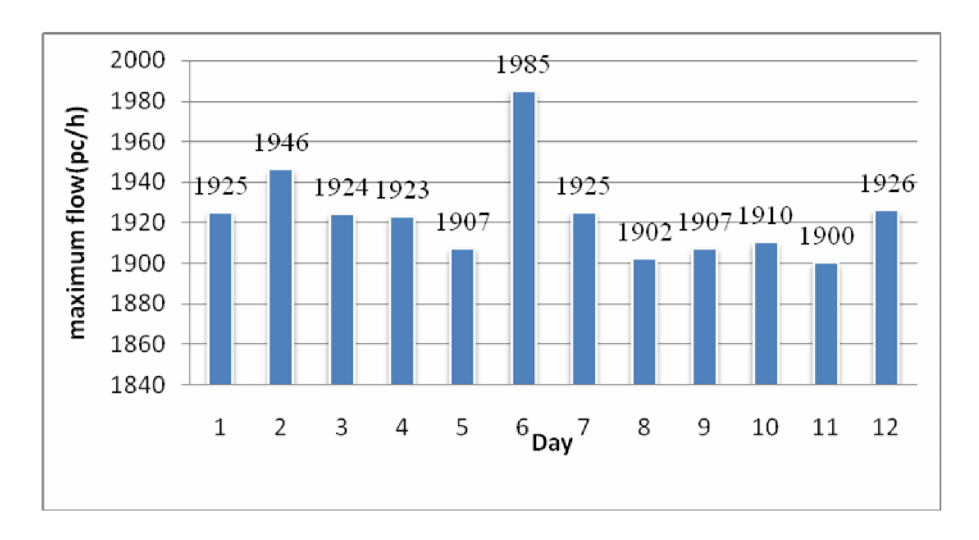


Figure 5.4 Actual capacity (lane 2-Zahran street)

From figure 5.4 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

= (1925+1924+1923+1907+1925+1902+1907+1910+1900+1926)/10 =1915 pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

C-Lane 4:-

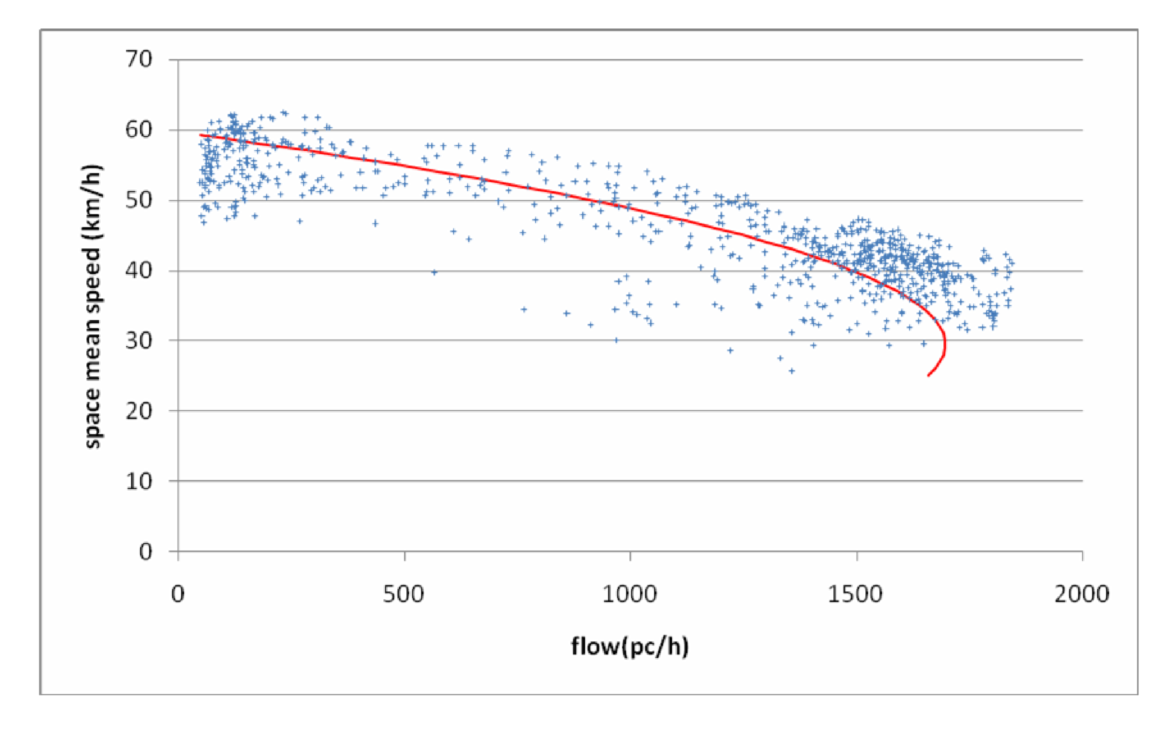


Figure (5.5) speed-flow model for lane 4-Zahran street

Minitab outputs for flow (q) -speed (v) model for lane 4 of Zahran Street are shown in table 5.4.

The derived regression equation (confidence interval =95%) is:-

$q = 253.6 + 96.80\ v - 1.67\ v^2$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 314.329 R-Sq = 73.8% R-Sq(adj) = 73.7%

Table (5.4):-Minitab outputs for analysis of variance (lane 4–Zahran street)

Source	DF	SS	MS	F	P
Regression	**2**	**293087545**	**146543773**	**1483.19**	**0.000**
Error	**1055**	**104237043**	**98803**		
Total	**1057**	**397324589**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 253.6 + 96.80\ v - 1.67\ v^2$

$dq/dv = 96.80 - 3.34\ v$

$dq/dv = 0 = 96.80 - 3.34\ v$ ………. $v_m = 29.98$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation , we could find theoretical capacity(maximum flow)

$q = 253.6 + 96.80\ v - 1.67\ v^2 = 253.6 + 96.80\ (28.98) - 1.67\ (28.98)^2$

$= 1654$pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate value of free flow speed.

$q = 253.6 + 96.80\ v - 1.67\ v^2 = 0$………$v = FFs = 60.40$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period.

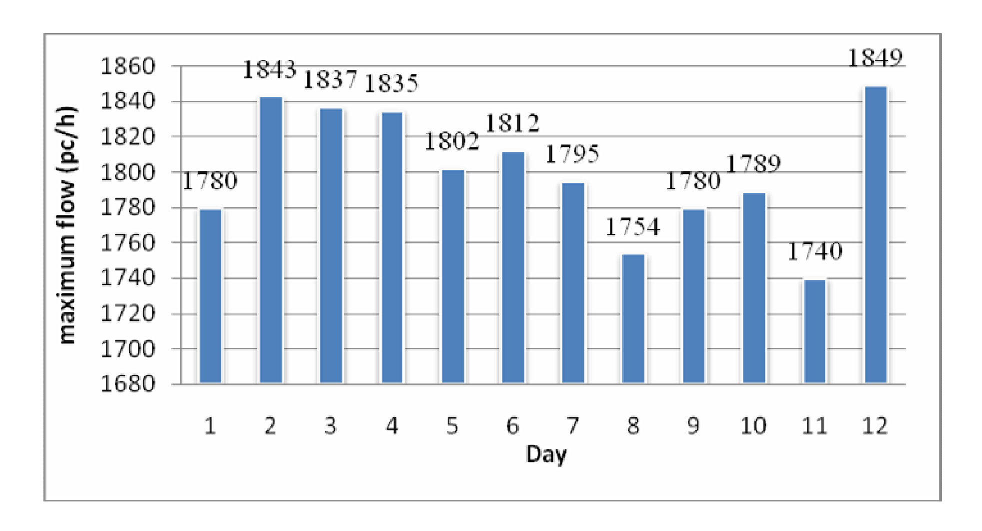


Figure (5.6) Actual capacity lane 4-Zahran street

From figure 5.6 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

q = (1780+1843+1837+1835+1802+1812+1780+1789+1795+1849)/10 = 1813 pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

The results of capacity analysis for Zahran Street are summarized in table 5.5 .

Table (5.5):- Results of capacity analysis for Zahran street

	R-Sq(adj)	P-value	Actual capacity	Theoretical capacity	FFS
Lane 1	0.922	0	1535	1413	60.60
Lane 2	0.943	0	1915	1863	67.97
Lane 4	0.737	0	1813	1654	60.40

Models were created using Quadratic regression analysis to represent the relationship between flow and speed The relationship between speed and flow is related with (R-Sq = 0.737-0.943) coefficient of determination. Speed is inversely related to flow. Statistical analysis indicated that flow has a significant effect on speed ($P<0.05$).The values of free flow speed for lane 1 and lane 4 were close to the posted speed (60 km/h) for the section. Results show that there is difference between actual and theoretical capacity values due to instability of flow near capacity.

5.3.2 Queen Alia Street.

A- Lane 1:

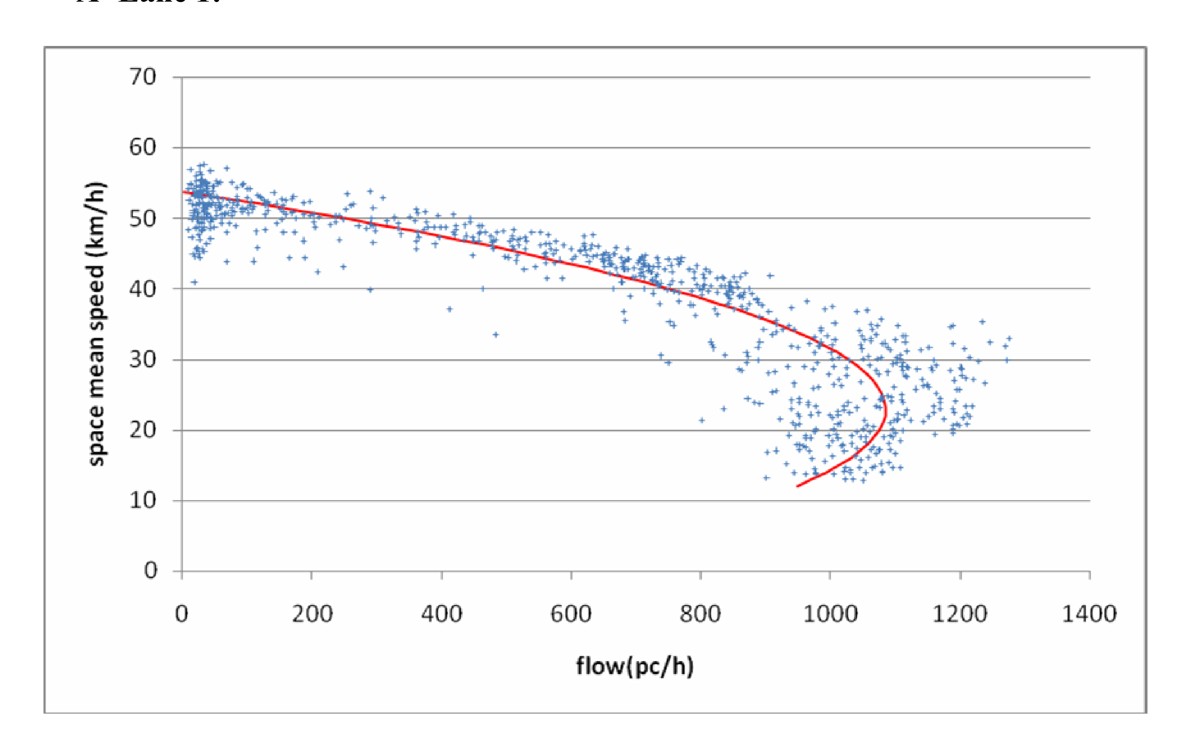


Figure (5.7) Speed-flow model for lane 1-queen Alia Street

Minitab outputs for flow (q) -speed (v) model for lane 1 of Queen Alia Street are shown in table 5.6.

The derived regression equation (confidence interval =95%) is:-

$$q = 492.1 + 50.97\ v - 1.11\ v^2$$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 140.379   R-Sq = 87.5%   R-Sq(adj) = 87.5%

Table (5.6):-Minitab outputs for analysis of variance (lane 1–Queen Alia Street)

Source	DF	SS	MS	F	P
Regression	**2**	**146688541**	**73344270**	**3721.88**	**0.000**
Error	**1064**	**20967447**	**19706**		
Total	**1066**	**167655988**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 492.1 + 50.97\ v - 1.11\ v^2$

$dq/dv = 50.97 - 2.22\ v$

$dq/dv = 0 = 50.97 - 2.22\ v$ ………. $v_m = 23.10$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation , we could find theoretical capacity(maximum flow)

$q = 492.1 + 50.97\ v - 1.110\ v^2 = q = 492.1 + 50.97\ (23.10) - 1.11\ (23.10)^2 = 1077$ pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = 492.1 + 50.97\ v - 1.110\ v^2 = 0$………$v = FFs = 54.10$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

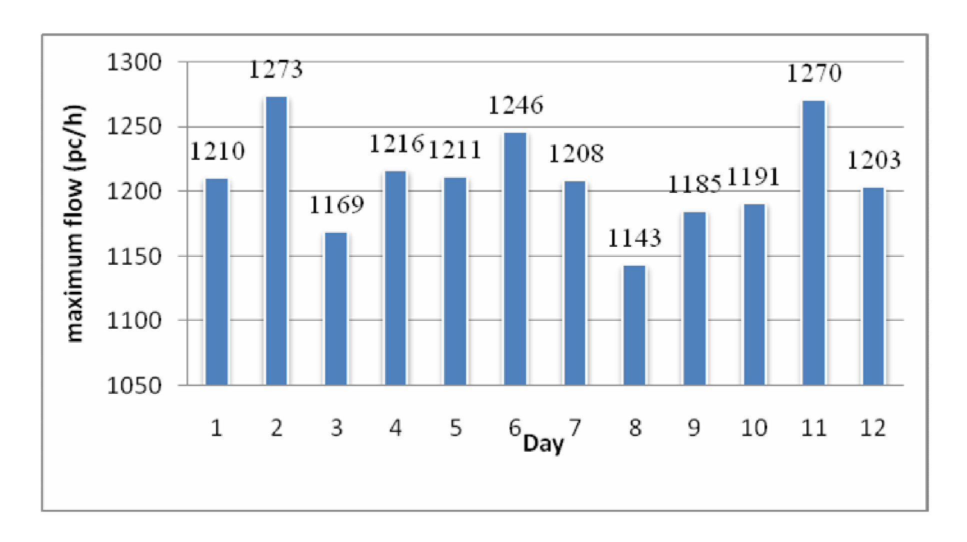


Figure (5.8) Actual capacity lane 1-queen Alia Street

From figure 5.8 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

= (1210+1216+1211+1246+1208+1185+1191+1203)/8 = 1208 pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

B-Lane 2:-

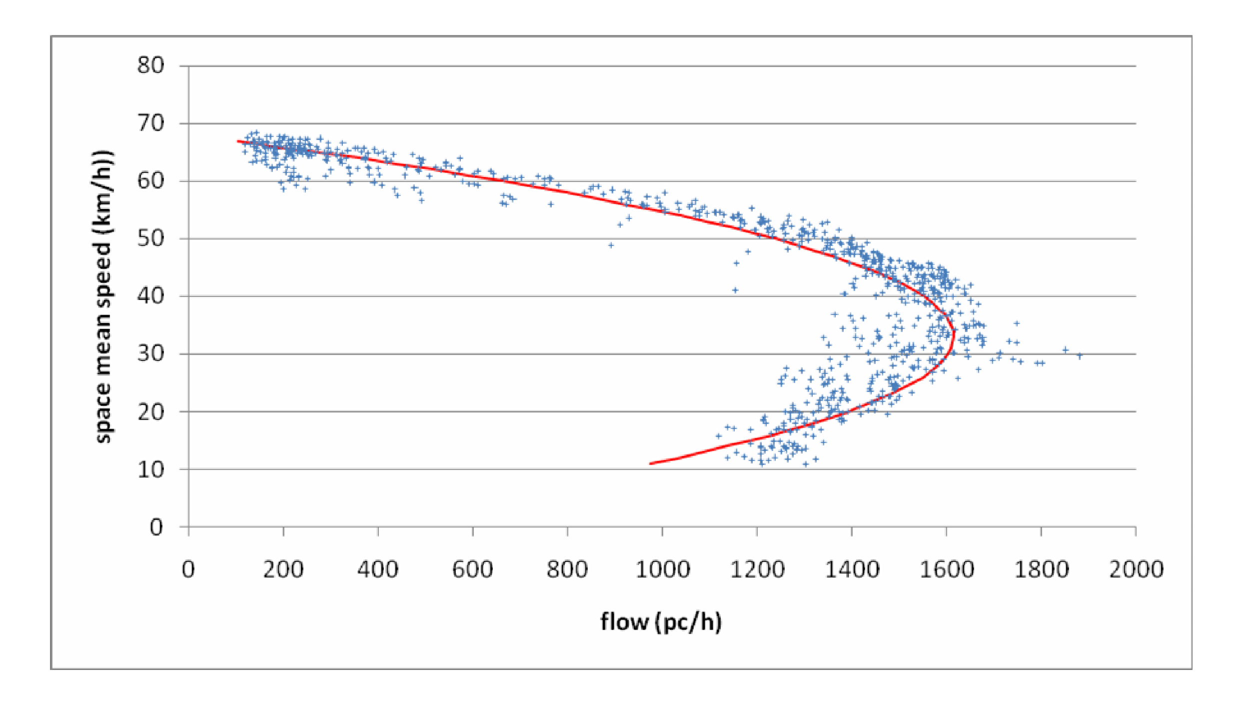


Figure (5.9) speed-flow model for lane 2-queen Alia street

Minitab outputs for flow (q) -speed (v) model for lane 2 of Queen Alia Street are shown in table 5.7.

The derived regression equation (confidence interval =95%) is:-

$q = 129.3 + 89.29\ v - 1.33\ v^2$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 132.64 R-Sq = 93.2% R-Sq(adj) = 93.2%

Table (5.7):-Minitab outputs for analysis of variance (lane 2–Queen Alia Street)

Source	DF	SS	MS	F	P
Regression	**2**	**255662474**	**127831237**	**7265.78**	**0.000**
Error	**1059**	**18631618**	**17594**		
Total	**1061**	**274294092**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 129.3 + 89.29\ v - 1.33\ v^2$

$dq/dv = 89.29 - 2.67\ v$

$dq/dv = 0 = 89.29 - 2.67\ v$ ………. $v_m = 33.02$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation , we could find theoretical capacity(maximum flow)

$q = 129.3 + 89.29\ v - 1.33\ v^2 = 129.3 + 89.29\ (33.02) - 1.33\ (33.02)^2$

$= 1619$ pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = 129.3 + 89.29\ v - 1.33\ v^2 = 0$……..$v = FFs = 68.20$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

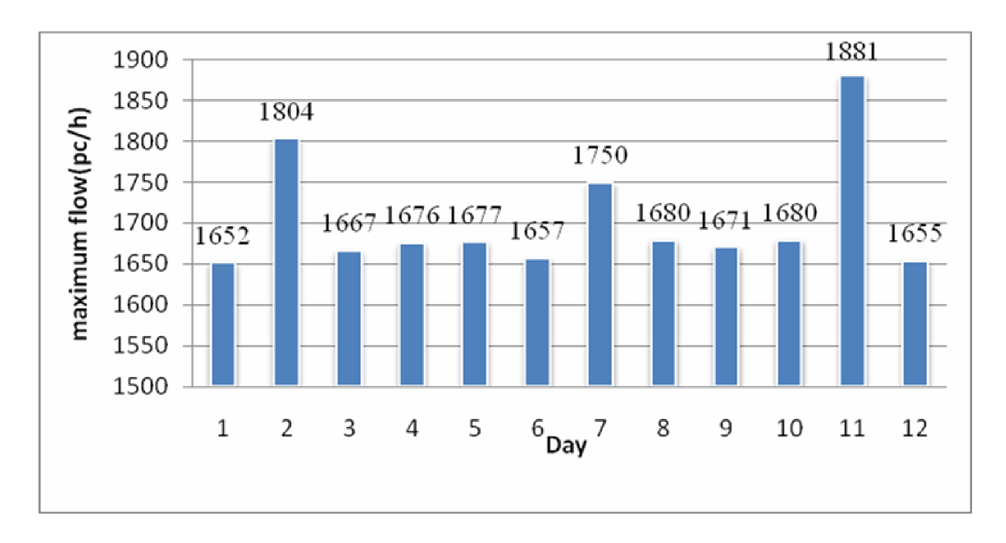


Figure (5.10) Actual capacity lane 2-queen alia street

From figure 5.10 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

$q = (1652+1667+1676+1677+1657+1680+1671+1680+1655)/9 = 1668$ pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

C-Lane 3:

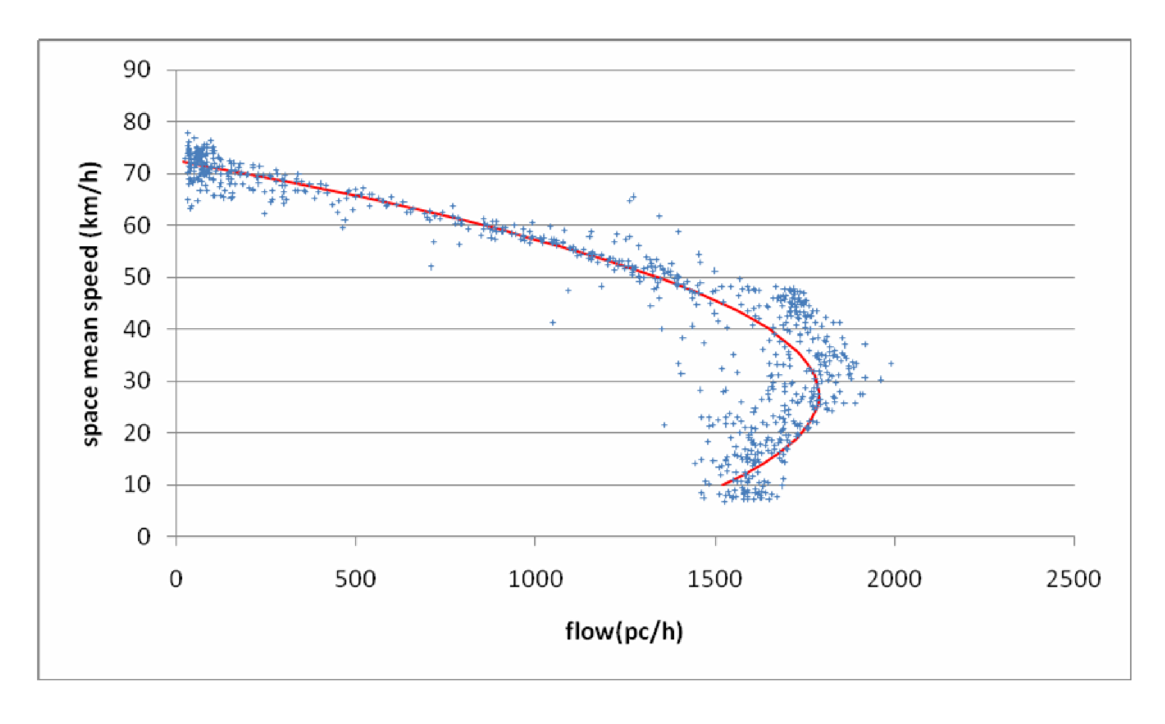


Figure (5.11) speed-flow model for lane 3-queen Alia Street

Minitab outputs for flow (q) -speed (v) model for lane 3 of Queen Alia Street are shown in table 5.8.

The derived regression equation (confidence interval =95%) is:-

$$q = 1078 + 50.97\ v - 0.91v^2$$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 168.499 R-Sq = 93.5% R-Sq(adj) = 93.5%

Table (5.8):-Minitab outputs for analysis of variance (lane 3–Queen Alia Street)

Source	DF	SS	MS	F	P
Regression	**2**	**431943228**	**215971614**	**7606.77**	**0.000**
Error	**1058**	**30038764**	**28392**		
Total	**1060**	**461981992**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 1078 + 50.97\ v - 0.91\ v^2$

$dq/dv = 50.97 - 1.82\ v$

$dq/dv = 0 = 50.97 - 1.82\ v$ ……… $v_m = 28.00$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation, we could find theoretical capacity (maximum flow).

$q = 1078 + 50.97\ v - 0.91\ v^2 = q = 1078 + 50.97\ (28.00) - 0.91\ (28)^2$

$= 1794$ pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = 1078 + 50.97\ v - 0.9063\ v^2 = 0$………$v = FFs = 72.62$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

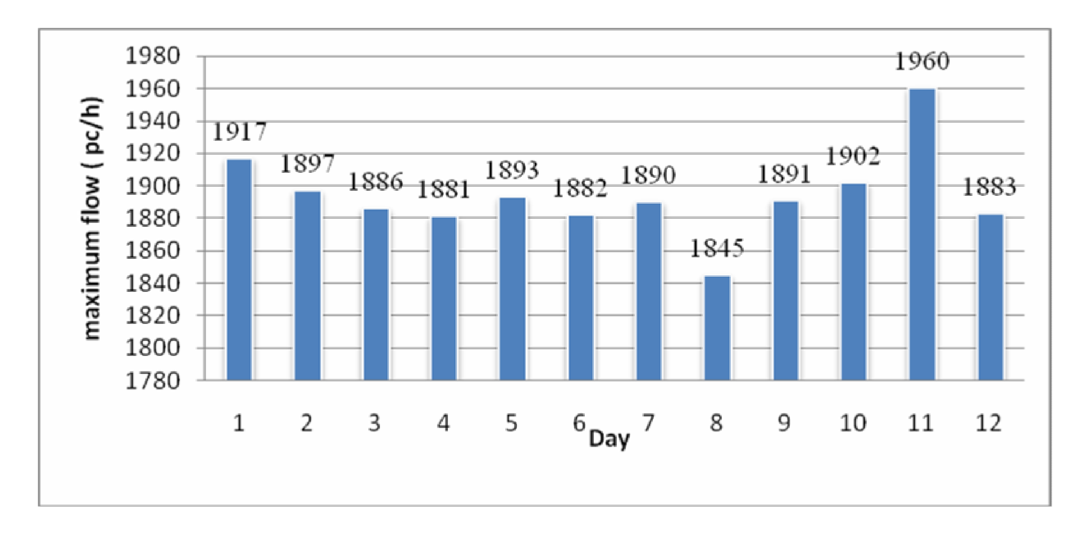


Figure (5.12) Actual capacity lane 3-queen Alia Street

From figure 5.12 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

= (1917+1897+1886+1881+1893+1882+1890+1891+1902+1883/10 = 1893 pc/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

D-Lane 4:

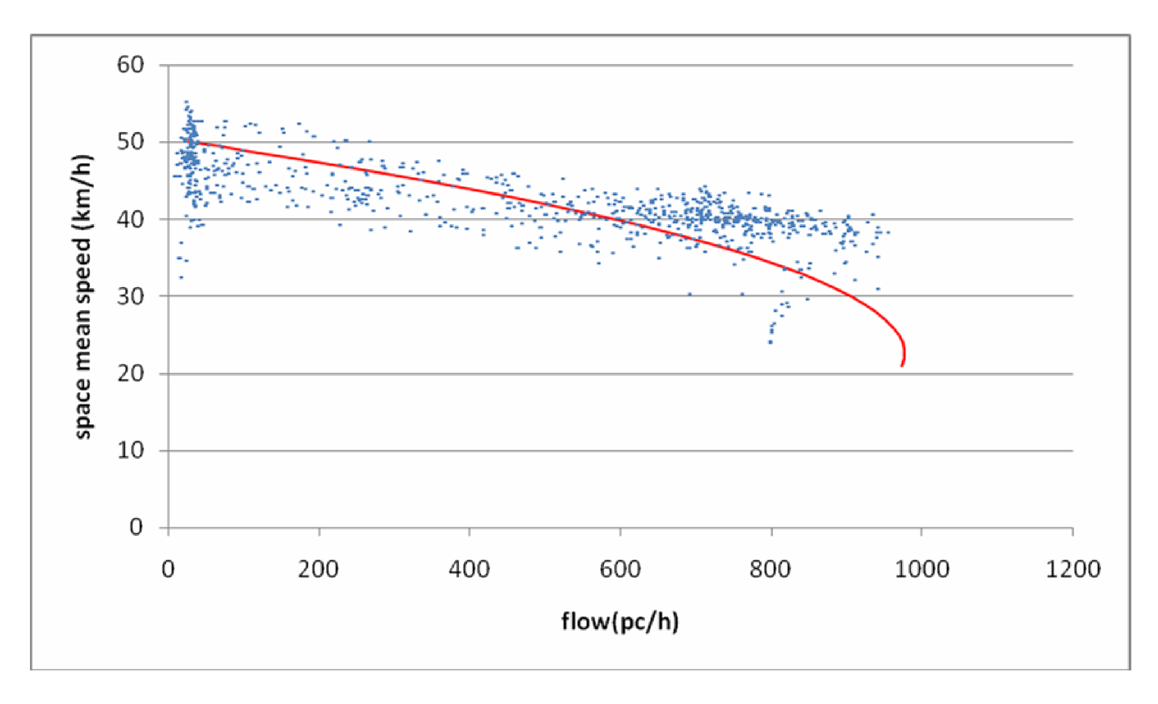


Figure (5.13) speed - flow model for lane 4 - Queen Alia Street

Minitab outputs for flow (q) -speed (v) model for lane 4 of Queen Alia Street are shown in table 5.9.

The derived regression equation (confidence interval =95%) is:-

$q = 473.3 + 51.62\ v - 1.20\ v^2$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 195.23 R-Sq = 60.8% R-Sq (adj) = 60.8%

Table (5.9):-Minitab outputs for analysis of variance (lane 4 –Queen Alia Street)

Source	DF	SS	MS	F	P
Regression	**2**	**60208976**	**30104488**	**789.85**	**0.000**
Error	**1017**	**38762286**	**38114**		
Total	**1019**	**98971262**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 473.3 + 51.62\ v - 1.20\ v^2$

$dq/dv = 51.62 – 2.40\ v$

$dq/dv = 0 = 56.32 – 2.63\ v$ ………. $v_m = 21.50$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation , we could find theoretical capacity(maximum flow)

$q = 473.3 + 51.62\ v - 1.202\ v^2 = q = 473.3 + 51.62\ (21.50) - 1.202\ (21.50)^2$

$= 1027$ pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = 473.3 + 51.62\ v - 1.20\ v^2 = 0$………$v = FFs = 50.70$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

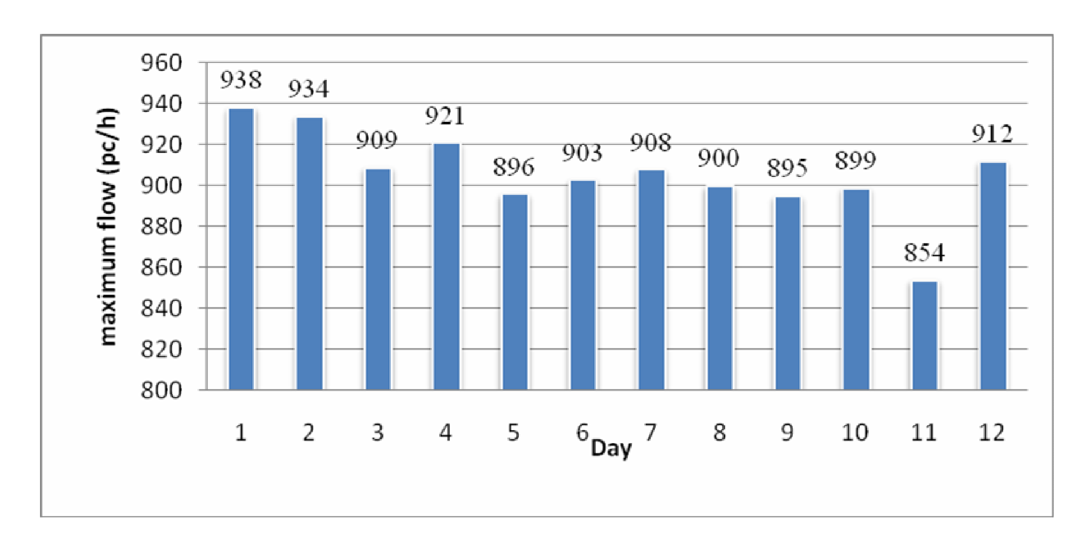


Figure (5.14) Actual capacity lane 4-queen Alia Street

From figure 5.14 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

= (909+921+896+903+908+900+895+899+912)/9 = 905 pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

E-Lane 5:

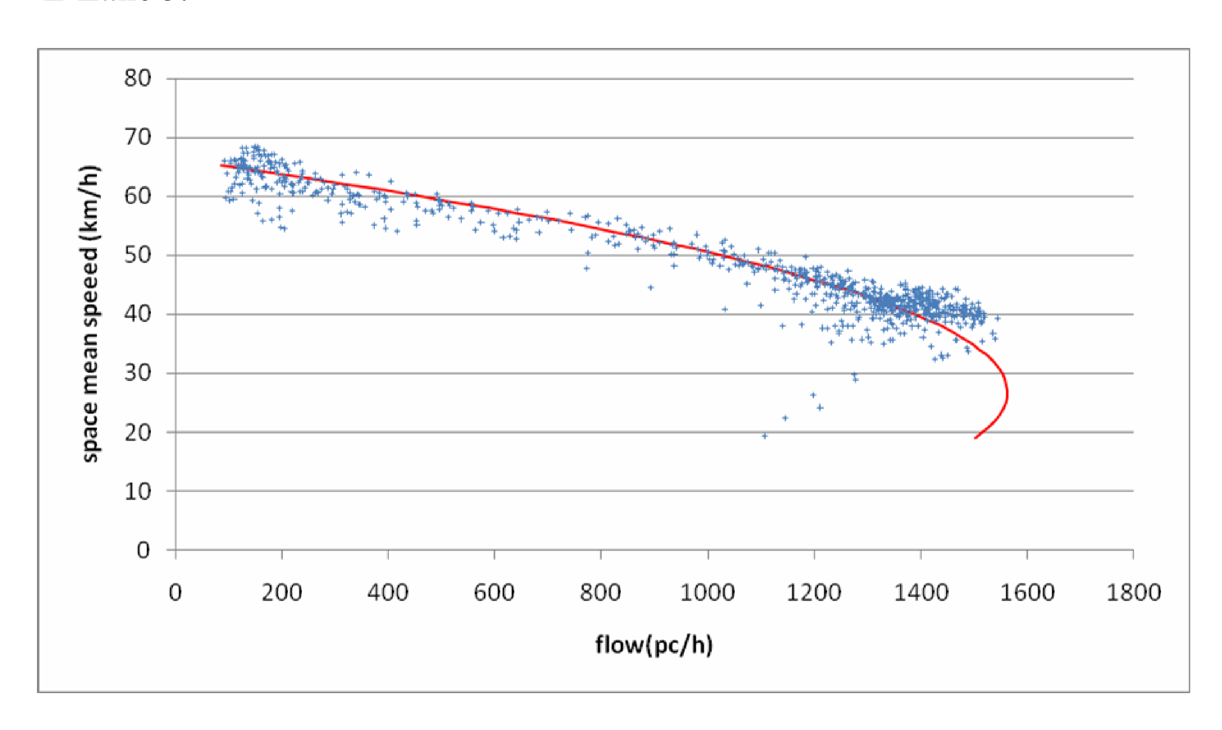


Figure (5.15) speed - flow model for lane 5 - Queen Alia Street

The derived regression equation (confidence interval =95%) is:-

$q = 461.7 + 68.76\ v - 1.15\ v^2$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 133.960 R-Sq = 92.0% R-Sq (adj) = 92.0%

Minitab outputs for flow (q) -speed (v) model for lane 5 of Queen Alia Street are shown in table 5.10.

Table (5.10):-Minitab outputs for analysis of variance (lane 5 –Queen Alia Street)

Source	DF	MS	SS	F	P
Regression	**2**	**219930694**	**109965347**	**6127.78**	**0.000**
Error	**1064**	**19093888**	**17945**		
Total	**1066**	**239024582**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 461.7 + 68.76\ v - 1.09\ v^2$

$dq/dv= 68.76 – 2.18\ v$

$dq/dv = 0 = 68.76 – 2.18\ v$ ………. v_m= 28.60km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation , we could find theoretical capacity(maximum flow)

$q = 461.7 + 68.76\ v - 1.09\ v^2 =$ $q = 461.7 + 68.76\ (28.60) - 1.09\ (28.60)^2$

= 1556 pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = 461.7 + 68.76\ v - 1.09\ v^2 = 0 \ldots\ldots\ldots v = FFs = 65.85$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

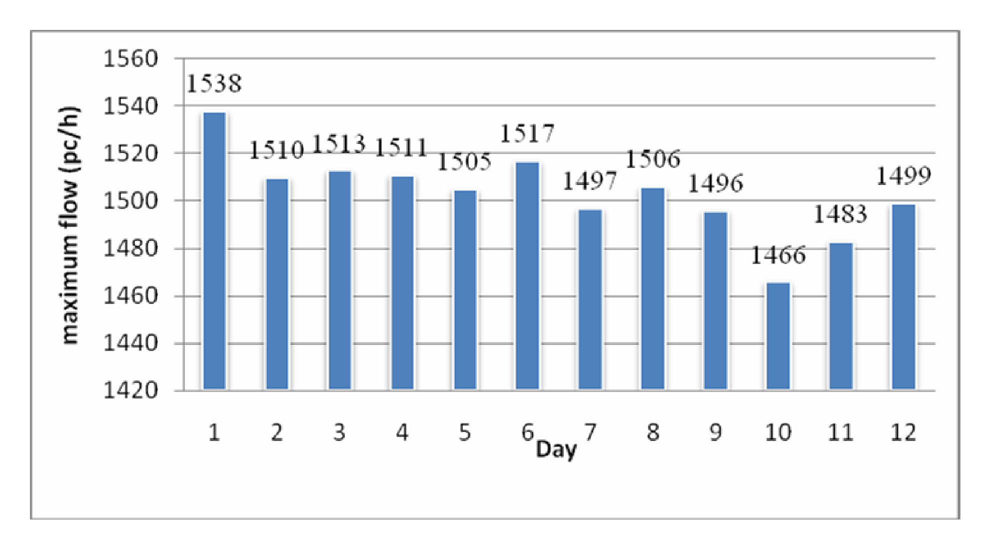


Figure (5.16) Actual capacity lane 5-queen Alia Street

From figure 5.16 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

$q = (1510+1513+1511+1505+1517+1497+1506+1496+1483+1499)/9$

$= 1504$ pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

F-Lane 6:

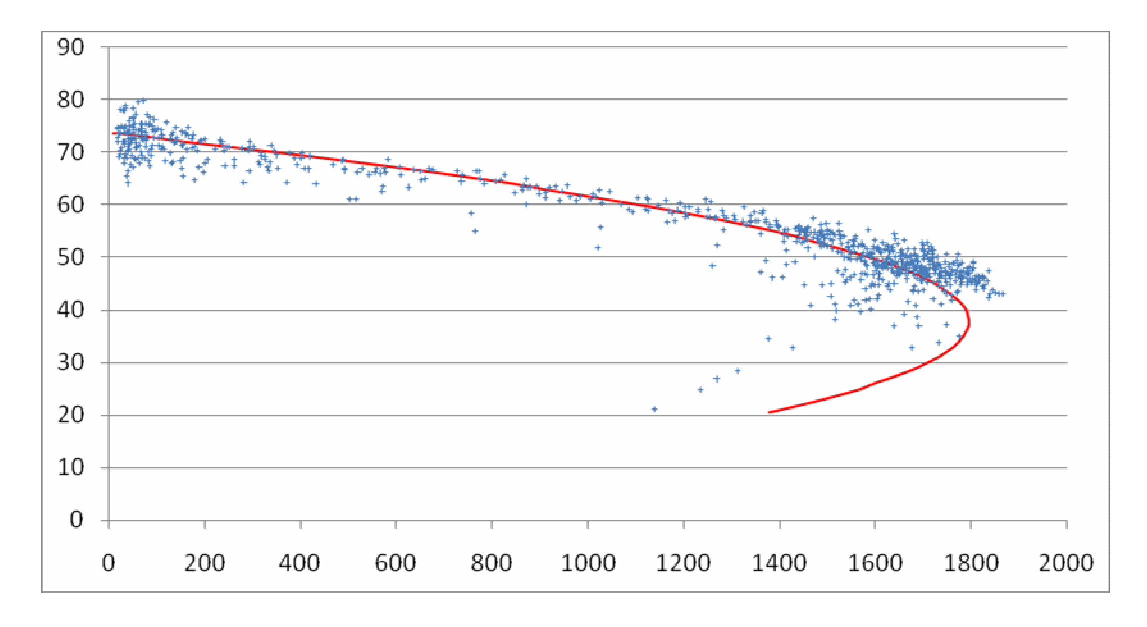


Figure (5.17) speed - flow model for lane 6 - Queen Alia street

The derived regression equation (confidence interval =95%) is:-

$$q = -42.8 + 96.67\, v - 1.28\, v^2$$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 186.770 R-Sq = 91.7% R-Sq (adj) = 91.7%

Minitab outputs for flow (q) -speed (v) model for lane 6 of Queen Alia Street are shown in table 5.11.

Table (5.11):-Minitab outputs for analysis of variance (lane 6 –Queen Alia Street)

Source	DF	SS	MS	F	P
Regression	2	409098770	204549385	5863.88	0.000
Error	1056	36836394	34883		
Total	1058	445935164			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$$q = - 42.8 + 96.67\ v - 1.28\ v^2$$

$$dq/dv = 96.67 – 2.58\ v$$

$$dq/dv = 0 = 105.40 - 2.79\ v \ldots\ldots\ldots\ v_m = 37.46\ km/h$$

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation, we could find theoretical capacity (maximum flow).

$$q = - 42.8 + 96.67\ v - 1.28\ v^2 = - q = - 42.8 + 96.67\ (37.46) - 1.28\ (37.46)^2$$

$$= 1772\ \ pcu/h$$

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$$q = - 42.8 + 96.67\ v - 1.28\ v^2 = 0\ldots\ldots\ldots v = FFs = 74.66\ km/h$$

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

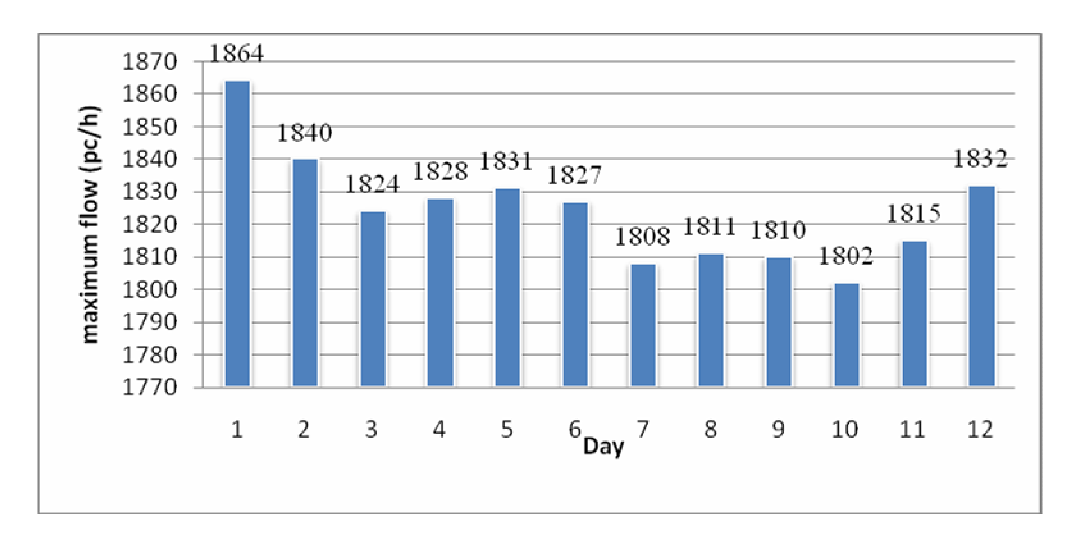


Figure (5.18) Actual capacity lane 6-Queen Alia Street

From figure 5.16 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

q = (1840+1824+1828+1831+1827+1808+1811+1810+1815+1832)/10 =

1823pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

The results of capacity analysis for Queen Alia street lanes were summarized in table (5.12)

Table (5.12):- Results of capacity analysis for Queen Alia Street

	R-Sq(adj)	P-value	Actual capaci ty	Theoretical capacity	FFS
Lane 1	0.875	0.000	1208	1077	54.10
Lane 2	0.932	0.000	1668	1619	68.20
Lane 3	0.935	0.000	1893	1794	72.62
Lane 4	0.608	0.000	905	1027	50.70
Lane 5	0.920	0.000	1504	1556	65.85
Lane 6	0.917	0.000	1823	1772	74.66

Models were created using Quadratic regression analysis to represent the relationship between flow and speed. The relationship between speed and flow is related with (R-Sq = 0.60-0.935) coefficient of determination and Speed is

inversely related to flow. R-sq value for lane 4 indicates that other factors affect speed on this lane like, stoppage, parking etc... . Statistical analysis indicated that flow has a significant effect on speed ($P<0.05$).The values of free flow speed for lane 3and lane 6 were high because the interruption for traffic flow is low on this lane (nearest to median) the values of free flow speed were reduced as we transit from left lanes to right lanes due to traffic interruption is increased as we transit from left lanes to right lanes. Results show that there a difference in actual and theoretical capacity values, this difference due to instability of flow near capacity.

5.3.3 Alquds Street.

A- Lane 1:

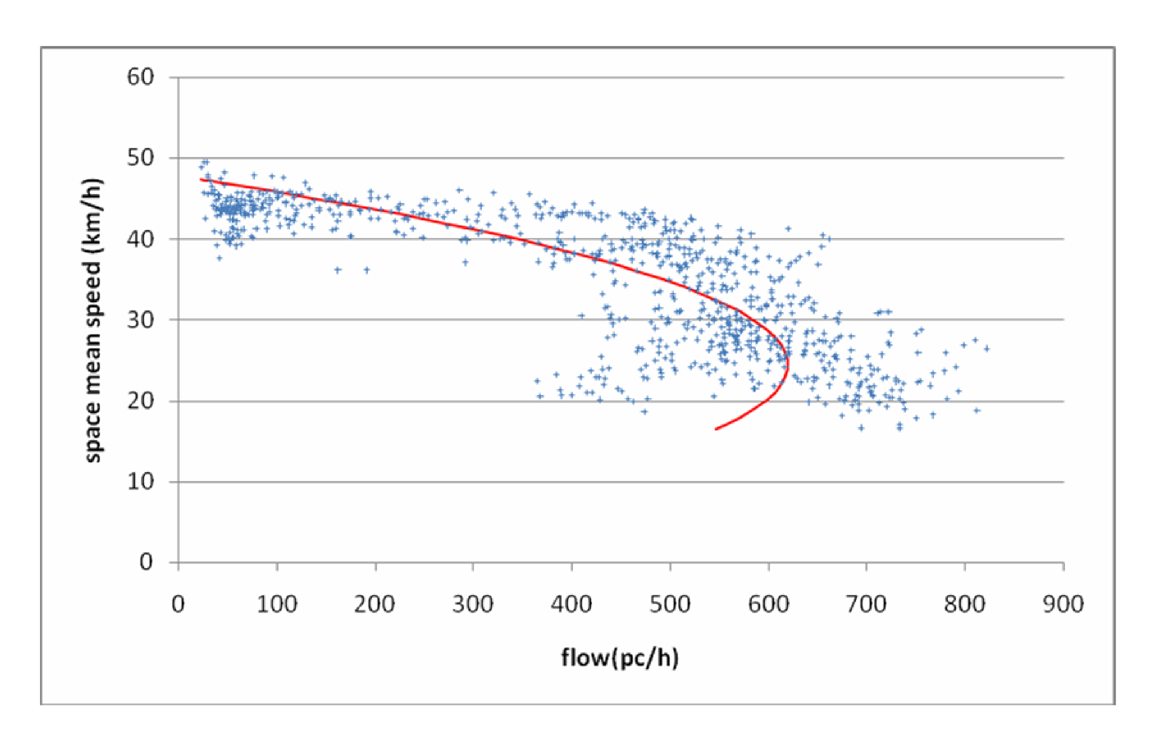


Figure (5.19) Speed - flow model for lane 1 – Alquds street

The derived regression equation (confidence interval =95%) is:-

$$q = 157.1 + 41.50\ v - 0.92\ v^2$$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 122.55 R-Sq = 68.6% R-Sq(adj) = 68.6%

Minitab outputs for flow (q) -speed (v) model for lane 1 of Alquds Street are shown in table 5.13.

Table (5.13): Minitab outputs for analysis of variance (lane 1 –Alquds Street)

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	**2**	**34885581**	**17442790**	**1161.26**	**0.000**
Error	**1061**	**15936816**	**15021**		
Total	**1063**	**50822396**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 157.1 + 41.50\ v - 0.92\ v^2$

$dq/dv = 41.50 – 1.86\ v$

$dq/dv = 0 = 41.50 – 1.86\ v$ ………. v_m= 23.30 km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation , we could find theoretical capacity(maximum flow).

$q = 157.1 + 41.50\ v - 0.9279\ v^2 = 621$ pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = 157.1 + 41.50\ v - 0.9279\ v^2 = 0$………$v = FFs = 48.23$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

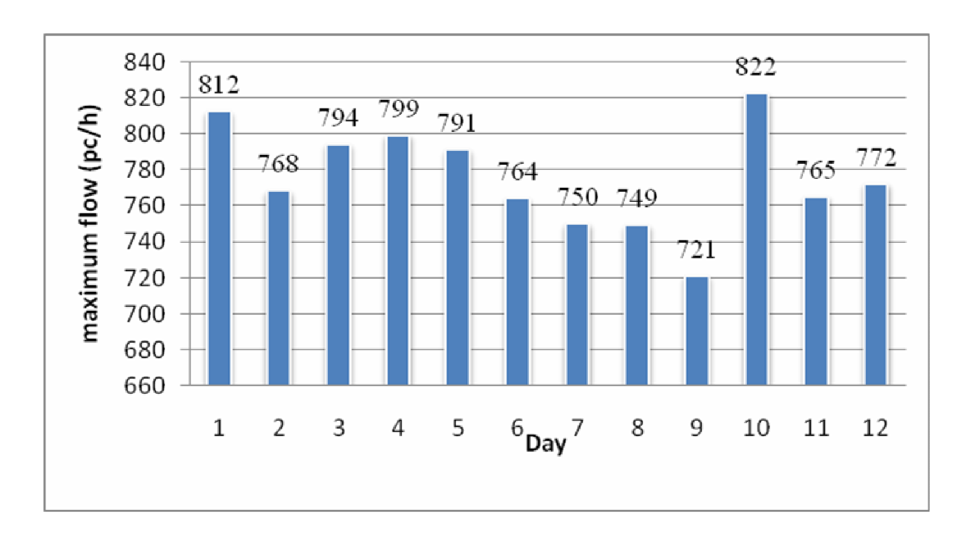


Figure 5.20 Actual capacity lane 1-Alquds street

From figure 5.20 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

= (812+768+794+799+791+764+750+749+765+772)/9 = 776 pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

B- Lane 2:

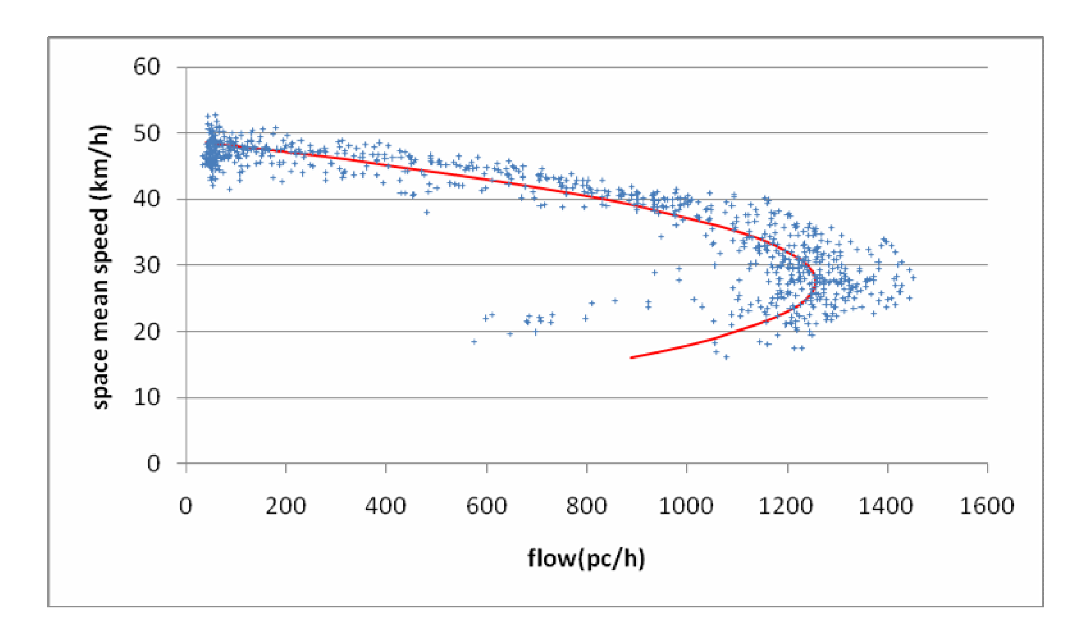


Figure (5.21) speed - flow model for lane 2 - Alquds street

The derived regression equation (confidence interval =95%) is:-

$q = -199.8 + 114.8\ v - 2.25\ v^2$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 166.405   R-Sq = 88.4%   R-Sq (adj) = 88.3%

Minitab outputs for flow (q) -speed (v) model for lane 2 of Alquds Street are shown in table 5.14.

Table (5.14):-Minitab outputs for analysis of variance (lane 2 – Alquds Street)

Source	DF	SS	MS	F	P
Regression	**2**	**216096443**	**108048221**	**3902.00**	**0.000**
Error	**1029**	**28493515**	**27690**		
Total	**1031**	**244589957**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = -199.8 + 114.8\ v - 2.25\ v^2$

$dq/dv = 114.80 - 4.50\ v$

$dq/dv = 0 = 114.80 - 4.50\ v$ ………. $v_m = 26.65$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation , we could find theoretical capacity(maximum flow)

$q = -199.8 + 114.8\ v - 2.25\ v^2 = 1264$ pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = -199.8 + 114.8\ v - 2.252\ v^2 = 0 \ldots\ldots\ v = FFs = 49.17$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

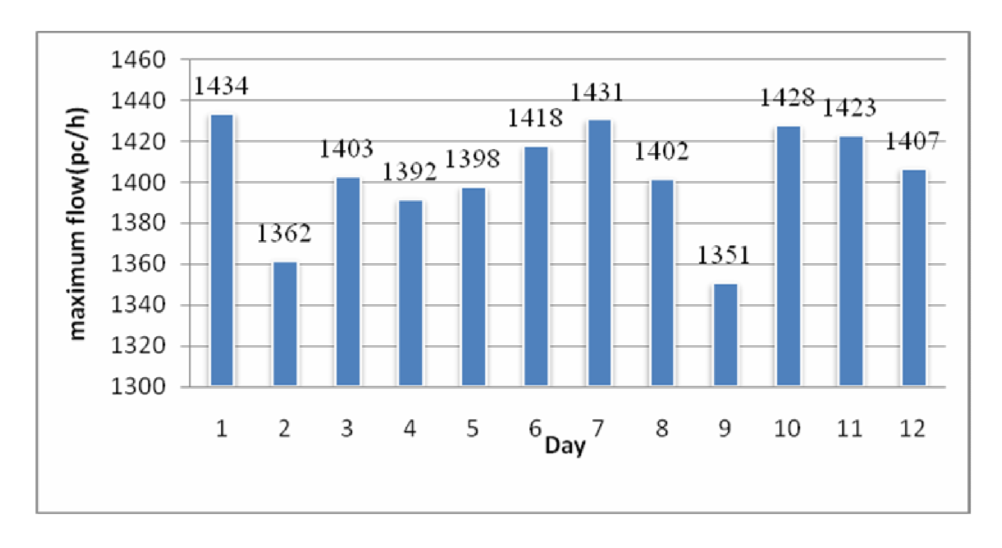


Figure 5.22 Actual capacity lane 2-Alquds street

From figure 5.22 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

$q = (1434+1403+1392+1398+1418+1431+1402+1428+1423+1407)/10$

$= 1414$ pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

C-Lane 3:

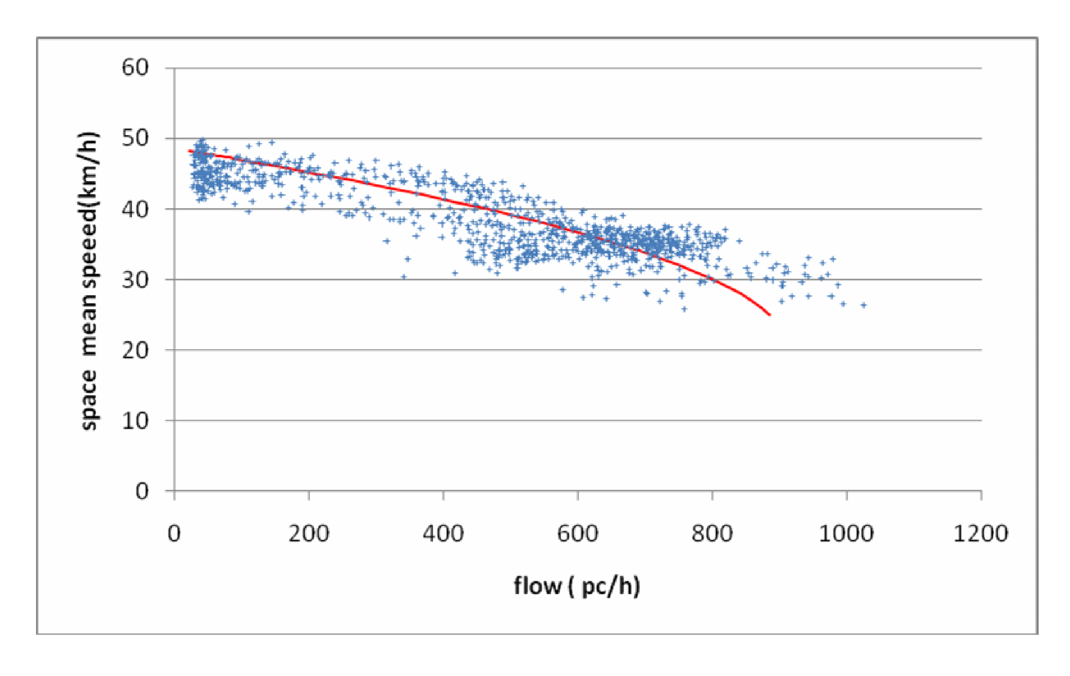


Figure (5.23) speed - flow model (lane 3–Alquds street)

The regression equation is

$q = 486.1 + 39.12\ v - 1.00\ v^2$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 129.100   R-Sq = 75.1%   R-Sq(adj) = 75.1%

Minitab outputs for flow (q) -speed (v) model for lane 3 of Alquds Street are shown in table 5.15.

Table (5.15):-Minitab outputs for analysis of variance (lane 3 –Alquds Street)

Source	DF	SS	MS	F	P
Regression	**2**	**52637869**	**26318935**	**1579.13**	**0.000**
Error	**1047**	**17450038**	**16667**		
Total	**1049**	**70087908**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 486.1 + 39.12\ v - 1.00\ v^2$

$dq/dv = 39.12 - 2\ v$

$dq/dv = 0 = 44.29 – 2.228\ v$ ……… $v_m = 19.56$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation , we could find theoretical capacity(maximum flow)

$q = 486.1 + 39.12\ v - 1.00\ v^2 = 870$ pc/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = 486.1 + 39.12\ v - 1.003\ v^2 = 0$………$v = FFs = 48.91$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

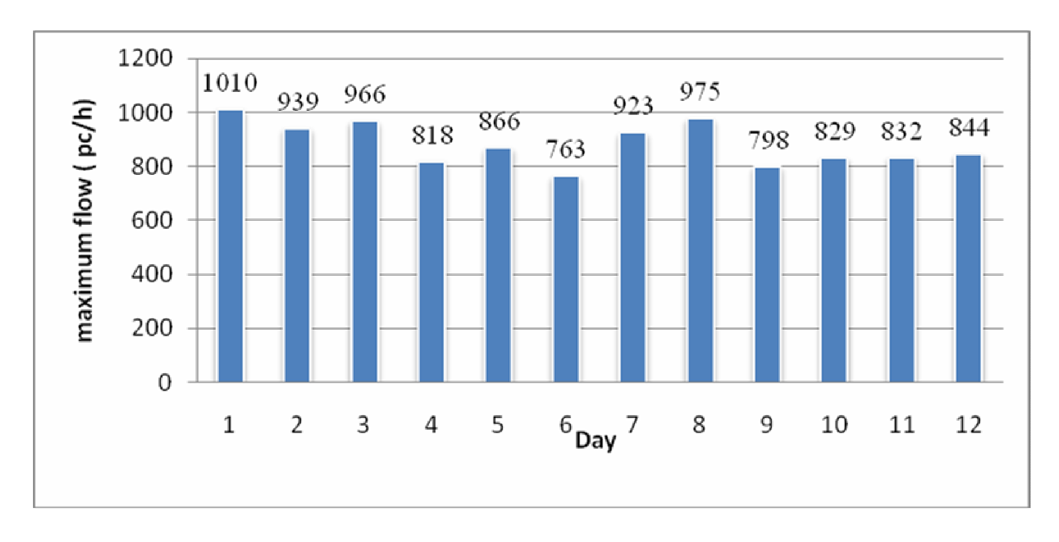


Figure (5.24) Actual capacity lane 3-Alquds street

From figure 5.24 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

= (939+966+866+923+975+798+829+832+844)/9 = 879 pcu/h

Note: - We exclude the outlier values to obtain accurate results

From resulted values of theoretical and actual capacity we noted that actual capacity is equal to theoretical capacity.

D-Lane 4:

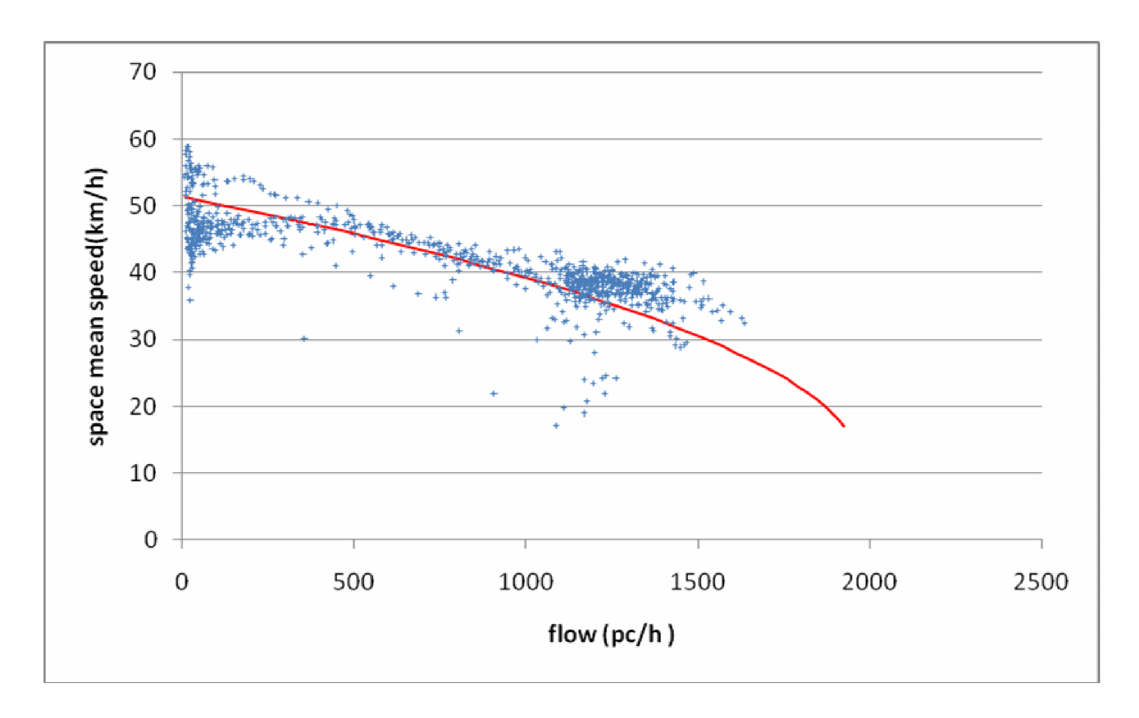


Figure (5.25) speed - flow model (lane 4–Alquds street)

The regression equation is

$q = 1763 + 25.73\ v - 1.12\ v^2$

Where:-

q= traffic flow (pcu/hour)

v= space mean speed (km/h)

S = 296.750 R-Sq = 67.0% R-Sq(adj) = 67.0%

Minitab outputs for flow (q) -speed (v) model for lane 4 of Alquds Street are shown in table 5.16.

Table (5.16):-Minitab outputs for analysis of variance (lane 4 –Alquds Street)

Source	DF	SS	MS	F	P
Regression	**2**	**203963815**	**101981907**	**1158.09**	**0.000**
Error	**1140**	**100388957**	**88060**		
Total	**1142**	**304352771**			

By differentiating the flow speed equation the theoretical capacity (maximum flow) and the free flow speed can be determined as follows.

$q = 1763 + 25.73\ v - 1.12\ v^2$

$dq/dv = 25.73 – 2.25\ v$

$v_m = 11.43$ km/h

Where v_m is the speed at theoretical capacity

Substitution v_m in flow speed equation, we could find theoretical capacity (maximum flow).

$q = 1763 + 25.73\ v - 1.123\ v^2 = 1810$ pcu/h

For evaluating free flow speed, we can equalize the flow –speed equation with zero and evaluate possible values of free flow speed.

$q = 1763 + 25.73\ v - 1.123\ v^2 = 0$………$v = FFs = 52.70$ km/h

For evaluating the actual capacity, we used excel program to view the average capacity for each day during study period. Results are shown below.

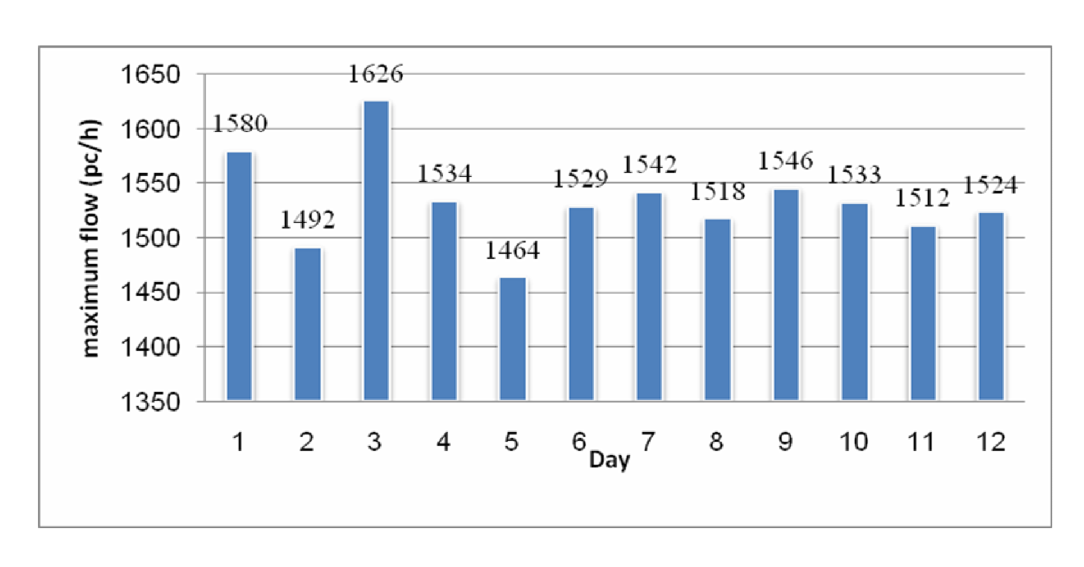


Figure 5.26 Actual capacity lane 4-Alquds street

From figure 5.26 we can calculate the actual capacity

Actual capacity = summation of maximum flow values for each day/no of days

= (1492+1534+1529+1542+1518+1512+1533+1546+1524)/9 = 1522 pcu/h

Note: - We exclude the outlier values to obtain accurate results.

From resulted values of theoretical and actual capacity we noted a difference between two values because the traffic flow is unstable near capacity.

The results of capacity analysis for Alquds street lanes are summarized in table (5.17).

Table (5.17):- Results of capacity analysis for Alquds Street

	R-Sq(adj)	P-value	Actual capacity	Theoretical capacity	FFS
Lane 1	0.68	0	776	621	48.23
Lane 2	0.88	0	1414	1216	49.17
Lane 3	0.75	0	879	870	48.91
Lane 4	0.67	0	1526	1810	52.70

Quadratic regression analysis was used to represent the relationship between flow and speed. The relationship between speed and flow is related with (R-Sq = 0.67-0.883) coefficient of determination. Speed is inversely related to flow. Statistical analysis indicated that flow has a significant effect on speed ($P<0.05$).Free flow speed had approximate values; this indicates that high interaction happened between vehicles on this section. Results show that there difference in actual and theoretical capacity values (except lane 3); this difference due to instability of flow near capacity. For lane 3, actual capacity is equal to theoretical capacity, because the model fit line was approximately passed on average point of unstable flow zone.

5.4 Comments on Capacity Analysis:-

a. In speed flow diagram, it is observed that many readings accumulate near capacity zone. This indicates that the studied sections are operating near, at and above capacity for long time in daylight.

b. There was a difference in actual and theoretical capacity values, due to instability of flow near capacity (unstable flow zone).

c. Location of lane affected lane capacity, left lanes (nearest lanes to median) had the highest capacity values, then the middle lane and then the right lanes (nearest lanes to sidewalk).This variations in capacity values are due to the interruption happened particularly, for right and middle lanes.

d. The value of estimated capacity used in Amman is 1800 veh/h/ln. This study evaluated the actual capacity; results indicate that for Amman, the actual capacity is less than design capacity. Table (5.18) compares the capacity values for the studied locations where, Actual capacity =summation of actual capacity values for section lanes / number of section lanes

Table (5.18): Approximate values for actual capacity and design capacity in Amman - (veh/h/ln)

	Actual capacity	design capacity
Zahran street	1680	1800
Queen alia street	1502	1800
Alquds street	1150	1800

5.5 Analysis the Effect Studied Factors on Lane Capacity:

5.5.1 Statistical Analysis Using Minitab:-

The study utilized MINITAB program for the statistical analysis to create a model that shows the effect of grade, lane width, number of lanes at each side, location of lane and the percentage of trucks passing through sections on the lane capacity by using multiple regression analysis with confidence interval (95%).

The values of actual lane capacity and selected factors which affect the capacity shown in table (5.19) were entered on Minitab program and analyzed resulting in a regression model of the following form.

Table (5.19): data of traffic flow and highway geometry

Actual lane capacity	Grade	lane width	%trucks	[1]Number of Lanes(each side)	loc 1[2]	loc 2[2]
1535	0.041	3.52	4.60	1	0	0
1915	0.041	3.10	5.20	1	1	0
1813	-0.041	3.55	7.00	1	1	0
1208	-0.008	2.80	7.90	0	0	0
1668	-0.008	3.10	7.60	0	0	1
1893	-0.008	2.90	4.50	0	1	0
905	0.008	2.75	7.60	0	0	0
1504	0.008	2.85	7.40	0	0	1
1823	0.008	2.95	5.90	0	1	0
776	0.023	2.65	8.10	1	0	0
1414	0.023	3.00	6.20	1	1	0
879	-0.023	2.65	5.10	1	0	0
1526	-0.023	2.95	6.65	1	1	0

[1] Number of lanes: - use (1) for two lanes each side, use (0) for 3 lanes each side

[2]-Location of lane: - (loc1, loc 2):-

a. (0, 0) for location3 (nearest lane to sidewalk)

b. (0,1) for location 2 (middle lane)

c. (1,0) for location 1 (nearest lane to median)

After entering the needed values, we used multiple regression analysis to show the effect of selected factors on actual capacity, the regression equation was performed, adjusted coefficient of determination and p-value were founded to make a judgment on the model.

Derived Regression Equation is:-

Estimated lane Capacity = -141.94 + 1006.22 grade + 635.41 lane width - 72.30* %trucks + a [1] +b [2]

(1) a = - 250.498 for two lanes per direction

a = 0.00 for three lanes per direction

(2) b = 512.9 for nearest lane to median (location 1)

b = 379.91 for middle lane (location 2)

b= 0.00 for nearest lane to sidewalk (location 3)

The Minitab outputs shown in table 5.20 are used to judge the adequacy of the model

Summary of Model

R-Sq = 93.97% R-Sq(adj) = 87.94%

Table (5.20): Minitab outputs" Analysis of Variance for the model"

Source	DF	F	P
Regression	6	15.577	0.002
grade	1	0.353	0.574
lane width	1	15.628	0.007
%trucks	1	6.066	0.048
2 lanes	1	7.367	0.035
loc 1	1	30.148	0.002
loc 2	1	7.976	0.030
Error	6		
Total	12		

The results of actual lane capacity and estimated lane capacity (estimated by performed model) values were summarized in table (5.21).

Table (5.21): "Actual and estimated lane capacity values"

Actual lane capacity	Estimated lane capacity
1535	1553
1915	1756
1813	1829
1208	1058
1668	1651
1893	1881
905	1064
1504	1522
1823	1827
776	729
1414	1588
879	899
1526	1491

5.5.2 Comments on the Developed Model:-

a. In general, all studied factors, ex cept grade, affected lane capacity because the regression P-value =0.002 < 0.05 And R-Sq (adj) = 87.94%.

b. In contradiction with all known practices grade was found not to affect lane capacity. This is explained by the lack of variations in grades values of the studied sites and , therefore, require further investigation

c. Remaining factors (lane width, percentage of trucks, number of lanes, and location of lane) had affect on capacity, P< (0.05).

d. Lane width and number of lanes were positively related to lane capacity.

e. Percentage of trucks was inversely related to lane capacity.

6. CONCLUSIONS

From the study results, the following conclusions can be derived:

- In Amman, the actual capacity is lower than design capacity.
- There is a difference between actual and theoretical capacity values, this difference happened due to instability of flow near capacity zone.
- Grade didn't affect lane capacity due to the lack of variations in grades values of the studied sites.
- The location of lane strongly affects lane capacity.
- Right lanes (nearest to sidewalk) have lowest values of capacity because it is highly interrupted by :-
    - ❖ Inappropriate geometric design for access and lane width
    - ❖ Interaction between vehicles.
    - ❖ Illegal and random stoppage and park (related to driver behavior in
    - ❖ Jordan).
- Lane width and number of lanes strongly affect lane capacity and are both positively related to it.
- Percentage of trucks strongly affects and is inversely related to lane capacity.

7. RECOMMENDATIONS

From the study results and conclusions, the following recommendations are formulated:

- Using new technologies that can give accurate and realistic traffic flow data from fields to build database that supports researchers in Jordan.
- In Jordan, we mustn't absolutely depend on international standards because it may be not effective for using in Jordan so, researches must begin to modify these standards.
- Design roads must be according to standards specially, lane width, parking and tapers of access to increase capacity of highways in Amman.
- Activate and increase the penalties in Amman that related to Illegal and random stoppage and park to increase highway capacity and decrease interruption.
- In Jordan, concerning foundations and researchers must begin to publish traffic and highway manuals that evaluate and control the design, operations and planning for transportation system.
- More factors affecting lane capacities were not addressed in this study .a further work is recommended to provide a full insight into the capacity issue.

8. REFERENCES

1. AASHTO (2001), **A Policy on Geometric Design of Highways and Streets**, 4th edition, Washington, D.C.: American Association of State Highway and Transportation Officials.

2. HCM (2000), Highway Capacity Manual, Transportation Research Board, National Research council, Washington, D.C.

3. Jasmina Bunevska and Marija M.Todorova, 2008 **"Speed-Flow Regression Models for Interrupted Traffic Stream**: **A Case Study"**, Department Of Traffic and Transport Engineering, Technical Faculty, University Of Bitola, Macedonia.

4. J. Asamer and M. Reinthaler, September 2010**," Estimation Of Road Capacity And Free Flow Speed For Urban Roads Under Adverse Weather Conditions"**, 13th International IEEE, Conference on Intelligent Transportation Systems ,Madeira Island, Portugal.

5. Jittichai, 2009,**" Analysis of Factors Affecting Street Bottleneck Capacity through Oblique Cumulative Plots"** Proceedings of the Eastern Asia Society for Transportation Studies, Vol.7,

6. Joonhyo Kim**,**2006**," A Capacity Estimation Method For Two-Lane, Two-Way Highways Using Simulation Modeling"** , Dissertation, Department Of Civil Engineering , Graduate School , Pennsylvania State University, USA.

7. Minitab statistical software version 16.

8. Garber N.J and Hoel L.A, 2010, **Traffic and Highway Engineering**, 4^{th} Edition, university of Virginia.

9. Ning Zhang and Xiaobao Yang, 2005, **"The Marginal Decrease of Lane Capacity With The Number Of Lanes On Highway"** Proceedings of The Eastern Asia Society For Transportation Studies, Vol. 5, pp. 739 – 749.

10. Satish Chandra , 2004, **"Capacity Estimation Procedure for Two-Lane Roads Under Mixed Traffic Conditions"** Paper No. 498, Indian road congress(IRC), India

11. Shyam Venugopal And Andrzej Tarko, 2001**" Investigation of Factors Affecting Capacity At Rural Freeway Work Zones"** Paper No. 2196 ,Purdue University**,** USA.

12. V. Thamizh Arasan and Reebu Zachariah Koshy, 2004, **"Simulation of Heterogeneous Traffic to Derive Capacity And Service Volume Standards For Urban Roads"** Paper No. 500, Indian road congress(IRC), India

	speed														
TIME	010	015	20	0025	0030	0035	0040	0045	0050	0055	0060	0065	0070	Up to 120	FLOW (PC/H)	AVERAGE SMS
12:00:00 ص - 01:00:00 ص	1	4	1	1	1	7	4	6	22	19	19	16	14	17	125.932	52.065
12:15:00 ص - 01:15:00 ص	3	3	2	0	0	3	7	8	16	18	11	16	8	14	104.196	50.645
12:30:00 ص - 01:30:00 ص	3	4	2	0	0	2	4	9	12	10	5	19	8	11	84.968	50.412
12:45:00 ص - 01:45:00 ص	4	4	2	0	1	4	5	8	13	6	2	16	4	10	76.419	47.322
01:00:00 ص - 02:00:00 ص	4	4	1	0	2	2	5	6	9	6	2	14	4	8	65.108	47.028
01:15:00 ص - 02:15:00 ص	2	4	0	0	2	2	2	1	8	2	1	13	4	5	44.658	48.396
01:30:00 ص - 02:30:00 ص	2	1	0	0	2	2	3	1	7	2	2	7	2	2	31.915	45.97
01:45:00 ص - 02:45:00 ص	0	1	0	0	1	0	2	2	5	3	2	9	6	3	32.350	53.951
02:00:00 ص - 03:00:00 ص	1	0	0	0	0	0	1	3	3	3	3	6	4	5	27.260	55.451
02:15:00 ص - 03:15:00 ص	4	1	0	0	0	1	1	4	4	3	2	5	5	6	33.840	49.392
02:30:00 ص - 03:30:00 ص	5	2	0	0	0	2	0	6	4	6	3	5	6	7	43.240	48.476
02:45:00 ص - 03:45:00 ص	5	2	0	0	0	2	0	5	4	6	3	3	6	9	42.816	49.351
03:00:00 ص - 04:00:00 ص	4	3	0	0	0	2	1	4	6	6	4	4	7	7	46.373	49.186

تأثيرعرض المسرب وعدد المسارب و الميل الطولي على سعة الطريق في عمان

إعداد

محمود حسن الخزاعلة

المشرف

الأستاذ الدكتور عدلي البلبيسي

ملخص

تبحث هذه الدراسة تأثير بعض خصائص مسار الطريق والتدفق المروري على سعةالمسرب لطرق مختارة في عمان ,عاصمة الأردن, ثلاثة مقاطع لطرق مزدحمة تم اختيارها لأغراض هذه الدراسة,الدراسة استخدمت وحللت فئتين من البيانات.الفئة الأولى وتشمل بعض تفاصيل مسارات الطريق للشوارع المختارة(الميل الطولي ,عرض المسرب وعدد المسارب) الفئة الثانية وتشمل معلومات عن التدفق المروري (حجم حركة المرور, سرعة حركة المرور,النسبة المئوية للشاحنات)لمقاطع الطرق المختارة,معلومات عن التدفق المروري أخذت من حلقة مجسات.

هنالك نوعان من نماذج الانحدار تم استخدامها لتحليل البيانات,النوع الاول هو تحليل الانحدار البسيط وتم استخدامه للتعرف على العلاقة بين التدفق المروري والسرعة على كل مسرب من الشوارع المختارة,النوع الثاني المستخدم من تحليل الانحدار كان تحليل الانحدار المتعدد الذي استخدم للتعرف على تأثير بعض الخواص لمسارات الطرق والتدفق المروري على سعة المسرب,هذه العوامل كانت (الميل الطولي ,عرض المسرب,عدد المسارب,موقع المسرب والنسبة المئوية للشاحنات المارة من خلال المقاطع المدروسة). اظهرت نتائج تحليل السعة بان قيم السعة التصميمية لطرق عمان هي أعلى من السعة الحقيقية ,الاختلاف بين قيم السعة الحقيقية والتصميمية يصل الى 35%.

اظهر التحليل بان السرعة والتدفق مرتبطان (عكسيا),تم استحدام نموذج للتعرف على تأثير بعض خواص مسار الطريق والتدفق المروري على سعة المسرب,عموما,النموذج الذي تم تكوينه أظهر بأنه هنالك تأثير واضح لمعظم العوامل التي تم اخذها بعين الاعتبار في الدراسة(ما عدا الميل الطولي) على سعة المسرب باستخدام فترة ثقة 95% مع معامل تحديد 87.94%, سعة كل مسرب كانت مختلفة عن المسرب الأخر حتى في نفس المقطع والأتجاه.